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SANITARY ENGINEERING COMES OF AGE

By P. H. McGauhey,[1] F. ASCE

SYNOPSIS

From its beginning in the 1920's, sanitary engineering as a specialty soon developed into an undergraduate option in the civil engineering curriculum. Inadequate preparation in the basic sciences, however, proved to be a serious limitation which educators first sought to overcome at the expense of more traditional applied civil engineering courses. After World War II, such courses gave way instead to socio-humanistic studies. Thus, the educational base of engineering was broadened and generalized at the expense of undergraduate specialization. Sanitary engineering then began a move into the graduate school. There it was confronted with both academic and financial problems that the predominantly undergraduate institutions are finding difficult to resolve in the face of limited student interest and of competition with the few larger institutions able to offer both the Master's and Doctoral degrees. Nevertheless, more than sixty engineering schools desire to continue their former undergraduate specialty offerings as a fifth year program leading to the M.S. degree. They are encouraged in this by the availability of funds for graduate student support and facilities appropriated at the federal level in hope of attracting students to the manpower-short profession of sanitary engineering.

On the other hand, they are discouraged by the cost of competing for the mere 413 total graduate students enrolled in sanitary engineering during 1960. The necessary investment in physical plant and staff, the need for subsidizing graduate students, and the lack of any professional yardstick by which to judge the adequacy of the program cause college administrators to hesitate.

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The "yardstick" dilemma could be overcome by accreditation of the first degree (M.S.) in sanitary engineering. Action to encourage this was taken in June 1960 at a Conference on Graduate Education of Sanitary Engineers held in Cambridge, Massachusetts. On that occasion, more than one hundred leaders in the field recommended that ASEIB take the necessary steps to attain accreditation of M.S. programs in sanitary engineering and related disciplines, preferably through ECPD.

In moving to the graduate school, sanitary engineering has grown in scope and quality. Nevertheless, the profession is justified in giving realistic attention to questions of accreditation, recruitment of students, and context of graduate programs.

At about the time the 1961 crop of Ph.D. candidates was born, sanitary engineering entered its sophomore year in college, destined as it turned out never to achieve the baccalaureate degree. Sanitary engineering didn't exactly flunk out of our undergraduate colleges; educators simply burned down the school house, or more precisely, the curriculum, before its senior year.

A brief generation ago the term "sanitary engineering" was little more than a concept in the mind of Gordon Fair of Harvard University. Elsewhere, water supply and sewerage were essentially problems in applied hydraulics just as they had been since the days of the Roman Empire. This was especially true of sewerage which in those carefree days was uncomplicated by biochemistry, BOD, oxygen transfer, and so forth. Instead, it was usually a straightforward civil engineering problem involving computation of the size and slope of sewer tile required to lead untreated sewage to the nearest watercourse. Here and there an Imhoff tank was being constructed and engineers, it may be added, were beginning to marvel at its nonhydraulic behavior.

Water supply engineering was somewhat more advanced. Engineers still went far afield with hydraulic structures to collect, transport, and distribute "pure" water. Nevertheless, the practice of chlorination was in its teens, and, in many places, was helping the slow sand filter to purify the public water supply. The rapid sand filter was sometimes being advocated for smaller cities, and water softening was a treatment process much talked about at technical meetings. It was recognized that bacteriological examination of water was a necessary control measure, and that the chemical reactions involved in flocculation, softening, and other treatment processes were of concern to the water supply engineer. But let's have none of these ions, electrons, and thermodynamic considerations. Atoms in those days behaved in a predictable and routine manner not so complicated as to intrude on the primary interest of the civil engineer.

Such was the undergraduate scene in the early 1920's and such was engineering practice in an area soon to emerge as sanitary engineering. However, giants had been at work in the field of water purification for several years. By the time the first would-be sanitary engineers entered graduate school the impact of men like Langelier, Black, Hazen, Buswell, Butterfield, Streeter, and Fair, to name but a few, suddenly burst upon the engineering profession. Almost overnight the need for a knowledge of sanitary chemistry and bacteriology on the part of the waterworks engineer became recognized. Furthermore, it was recognized that engineers stood on the threshold of an age of

sewage and industrial waste treatment, albeit still wondering what was going on in that infernal Imhoff tank, in sewage filters, in digesters, and in polluted waters.

The undergraduate schools of engineering were quick to recognize the inadequacy of a program which did not provide in its civil engineering curriculum room for specialization in this new area. Those who aspired to teach sanitary engineering hastened to improve their own backgrounds through courses in chemistry, bacteriology, epidemiology, microscopy, statistics, mathematics, and design. And as this knowledge alone proved inadequate to explain or to circumvent the problems of waste disposal, professors assumed also the responsibilities of research, little realizing, perhaps, that they were starting down an endless, although interesting and fruitful, road. Armed with an extension of their own backgrounds, and, happily, with the encouragement of the administrative officers of the engineering schools, they sought to meet the newly recognized need for sanitary engineering education by providing an option in the undergraduate curriculum of civil engineering. That it did not endure to achieve recognition by a designated B.S. degree came about in a fashion unrelated to its professional merits.

The time allotted for technical elective courses in the junior and senior years in most civil engineering curricula, from the late 1920's until the close of World War II, was reasonably adequate for the engineering and applied aspects of sanitary engineering. The difficulty was that the decision to specialize in sanitary engineering was usually made by the student too late to permit preparation in the background courses of biology and chemistry prior to his senior year, thus reducing seriously the scope of the specialization he might undertake. To overcome this dilemma, sanitary engineering professors sought to give suitable orientation to engineering students early in their programs in hope that their latent interest in the field might be aroused in time to arrange for necessary science courses at the lower division level. The alternate was to offer a five-year program or to impose a graduate year.

Lack of contact with beginning students led to failure in the objective of early orientation and the five-year program was never widely accepted as a solution to engineering's educational problems. Instead, the idea of a graduate year slowly gained in stature. Until its ultimate triumph in our philosophy of higher education, however, the need for undergraduate courses in sanitary chemistry and biology as a part of the undergraduate option in sanitary engineering endured. The problem became one of displacement of something else in order to make room for this chemistry and biology.

Civil engineering had long and traditionally been oriented toward structural engineering and toward the arts of drafting and surveying. Five courses in surveying were designed to prepare the civil engineer for just about any contingency afield, except "chiggers." Generally, his work began in the field. Then, when he had completed a suitable apprenticeship outdoors he might expect to move into the office and make use of the knowledge he was presumed to have acquired by such activity as drawing rivet heads three afternoons per week throughout his senior year.

Some "heretics," in sanitary engineering, made bold to suggest that the sanitary engineer might well do with less surveying and perhaps with less structural drafting in order to find time to strengthen his background in the sciences pertinent to his chosen field. The cries of anguish generated by this radical suggestion need not be cataloged here, nor is there any purpose in

repeating the arguments by which its adherents sought to dispel the fears that the engineering profession would suffer irreparable damage should one of the lopsided Frankenstein monsters so created, ever elect to call himself a civil engineer.

It is problematical how the proposed deviations from gospel might have ended had not the events which followed World War II confounded both the educational deviates and their more conservative colleagues, had not engineering educators been suddenly overwhelmed by a mass eagerness to confess their guilt before newly ascendent leaders of education. Some curious brainwashing which had been in progress for some years led them at that point in time finally to embrace the concept that those who study applied science emerge as inarticulate boors, trampling with their heavy boots the tender shoots of culture, peering insensitively through their infernal instruments in pursuit of low level goals, and generally befouling with their slide-rule minds the cultural atmosphere generated in some peculiar fashion by the easier courses in the university catalog. In any event, a re-appraisal of engineering education followed World War II. At that time sanitary engineering left the undergraduate scene for what is now generally agreed to be a more appropriate location in the graduate curriculum.

It should not be assumed that sanitary engineering was at any time exclusively an undergraduate option. From the very beginning, the difficulties previously described had the effect of encouraging graduate offerings at the M.S. level. Nevertheless, a considerable degree of specialization did exist at the undergraduate level, and as long as the philosophy of engineering education admitted of such specialization, many educators worked hard and not too ineffectively to give it professional stature. Looking back now over the breadth of environmental problems with which sanitary engineering was to become concerned, it is easy to see that it was destined to become increasingly a graduate program unless divorced entirely from civil engineering and established as an entirely new branch of engineering. Few, if any, sanitary engineers ever advocated such a course.

The re-appraisal of engineering curricula which followed World War II essentially terminated undergraduate concern with sanitary engineering as a specialized field. Of course, in most institutions a residue of electives remain available to the senior student who knows in advance that he will go on into graduate study in the field, but in general he begins his graduate year far less prepared than did his predecessor who had the undergraduate option. The result is that technically the M.S. degree today is somewhat degraded from its previous status in terms of breadth of experience. In depth, of course, it is probably superior both as a result of advances in understanding of basic principles, greater maturity of students, and higher educational attainments of the teaching staffs. In the case of the doctorate program, these two factors have evidently combined to give it greater technical stature than ever before.

Establishment of sanitary engineering almost exclusively as a graduate program has not resolved all of the old problems which beset it as an undergraduate option. Furthermore, new ones have derived from the broadened scope of the field, as air pollution, radiological health, industrial wastes, biological engineering, industrial hygiene, and many aspects of environmental control have been added to its original concern with water supply and sewerage. The problem of an early foundation in science has been partially met by development of a broader scientific base in engineering curricula. This, however, involves the physical sciences, hence, the student whose undergraduate

study has been in civil engineering, which represents the principal source of sanitary engineering graduate students, still enters the program with an inadequate background in the biological sciences. Hence, courses normally given an undergraduate number in university catalogs are required to make up this deficiency.

Now, a graduate student is normally permitted to include in his program a certain percentage of undergraduate upper division courses. But when he seeks to enroll in such courses in his area of deficiency, he is likely to find that he must first qualify by taking elementary lower division courses such as "General Biology 1A." Because this course carries no credit toward the advanced degree, is intended for freshmen in liberal arts but is oriented by the professor for beginning students in pre-medicine, and is paced to enable freshmen to make the adjustment from high school to the university, the graduate student becomes alarmed. When he finds this situation essentially repeated in other non-engineering areas, he becomes genuinely desperate.

Not that he is unwilling to undertake an adequate program of study; but he has a wife and two children, his financial resources are limited, and with an adult mind and a life expectancy of but three-score and ten, give or take a few years, he is reluctant to embark upon a program which appears best suited to a creature that might live a thousand years. He may well argue that 50% of the life expectancy of man is about the maximum a student can afford to spend in preparing himself for active participation in a profession within a society in which the planned obsolescence of man occurs at an increasingly early age. It is up to the department offering sanitary engineering to come to his rescue.

In doing so it often develops that the independent departments of science are little interested in the problem. Dedicated to his own graduate programs, condemned to teach large groups of general science students, possessing residual contempt for the applied sciences in spite of engineering's new look, the professor of "pure" science often demands to know how anyone can possibly presume to deal with biochemical matters unless he has taken . . . ? And he proceeds to catalog essentially the ladder of courses his own graduate students followed in their climb to the B.A. degree.

The result is that the sanitary engineering department must often provide on its own staff scientists with the competence to teach necessary subject matter. Hence, the engineering staffs of larger schools often include Ph.D. chemists and biologists who have become oriented and interested in the application of their knowledge to engineering problems. They present their material under engineering course titles. Although this device solves the academic problem by providing well oriented science taught by appropriate scientists, it nevertheless magnifies the size and cost of staff necessary to carry a sanitary engineering program at the graduate level and thus places at a disadvantage the smaller department which must call on a limited engineering staff to carry all aspects of its graduate program.

As sanitary engineering moves into graduate schools, some administrative and professional adjustments must be made. The predominantly undergraduate institution has, perhaps, found the transition most difficult. Whereas it may delay for a few seasons abandonment of the undergraduate option program, prolonged adherence to an obsolescent concept could endanger the accreditation of its civil engineering department. On the other hand, advancing the sanitary engineering program to the graduate years tends to force it into competition with that of a few larger institutions. Such competition may be

all but ruinous because of limited enrollments, inadequate financial resources, and the lack of any professional yardstick by which to judge the extent to which a program to be professionally adequate must meet the highest level of competition. A brief elaboration of each of these factors might be in order.

Number of Students.—Because the majority of undergraduates do not pursue further study, the number of students interested in sanitary engineering is reduced by the mere fact that it is a graduate program. This means that essentially no institution can justify a graduate program on the number of its own undergraduates which return for advanced study. It must draw upon the B.S. graduates of other schools; those which offer, as well as those which do not offer, a graduate program of their own.

That there is, in fact, competition for graduate students may be judged from the fact that in 1960 there were some 57 schools offering sanitary engineering to a total graduate enrollment of but 413. Because about 6% of this number are in one major institution it is obvious that not all of the 57 have going programs. Yet essentially all formerly successfully offered sanitary engineering work as an undergraduate option.

Mere survival, together with the fact that the small number of students intensifies the shortage of qualified sanitary engineers, impels these institutions to take steps to re-establish their programs at the graduate level in spite of the competition of others more favored by superior financial position, eminence of faculty, and well established excellence of program.

In spite of the need for increasing enrollments in our graduate schools to overcome current shortages of sanitary engineers, many are beginning to question whether enough students shall ever be interested to justify all of the institutions seeking to remain in the field of sanitary engineering. Obviously, the few more fortunate civil engineering departments in the United States could by no means handle all of the students, even if such an eventuality were educationally desirable, which it is not. Nevertheless, the profession must take a hard look to its future if the limited funds for support of graduate students are not to be so dissipated that excessive cost per student leads to a simple survival of the fittest.

Financial Problems.—The foregoing consideration is particularly significant because an almost universal need for financial aid to the graduate student has developed in recent years. How is such aid to be provided? In a few cases colleges have sought an answer by instituting a night program in order to make it available to self-supporting graduate students. Such students, however, normally hold full-time jobs during the day and consequently may take but one or, at most, two courses each semester. Thus, from the standpoint of the student, his degree program is stretched out over a discouragingly long period of time. As a unified co-ordinated educational experience it likewise leaves much to be desired. At best it is operative only at the M.S. level, all institutions requiring some full-time residence for the Ph.D.

For these reasons, and because of the constraints imposed on normal living, the concept of night programs of a professional grade generally meets with unfavorable faculty reaction. The tendency is to assign these night courses to practicing engineers and employees of health departments who, however competent in their own fields, have each his own brand of unfamiliarity with the educational objectives of a graduate program. Furthermore, to all other limitations of the night program is often added that of the unavailability of strong supporting courses unless many segments of the institution

participate, which is seldom the case. The result is that to be fully successful, a graduate program must be operated principally as a full-time day program, providing as best it may for financial aid to students.

United States Public Health Service (USPHS) traineeships, National Science Foundation (NSF) fellowships, and grants by various health departments to their own employees, together with teaching assistantships, fellowships, and scholarships offered by the colleges and universities themselves have financed an impressive number of graduate students in sanitary engineering. However, the greatest number of students have been financed through participation in sponsored research carried on by various faculty members under grants-in-aid or through contacts with various public and private agencies. Such agencies as the Atomic Energy Commission, the National Institutes of Health, the National Science Foundation, the Rockefeller Foundation, the Federal Housing Administration, the Corps of Engineers, the Navy, and the Air Force, as well as industrial associations and state agencies are among those sponsoring research related to sanitary engineering.

There is no doubt that the larger and better established sanitary engineering programs have attracted most of the support. Nevertheless, they also face inadequately resolved financial problems. In most cases the difficulty arises in making the tenure of the student coincident with the research contract which is to support him. The problem becomes one of admitting a graduate student in April and gambling that by late summer the research proposal will receive favorable action by the sponsor. This dilemma is avoided in a few institutions which, for other reasons, have established research laboratories or institutes staffed with full-time research personnel. These are capable of performing the investigative work of a contract even if no graduate students become available. Of course, there would be no particular objective in maintaining the facility if no graduate students came along, as there would be no need for the faculty which attracted the research in the first place.

But graduate students do come along, themselves attracted by the quality and range of faculty made possible by the research program. By keeping the full-time professional research staff always expandable, employment opportunities are open to graduate students each year in a going operation. The doctoral candidate readily finds interesting off-shoots of the main stream of faculty research which he may pursue independently, and if he needs advice concerning an appropriate subject for his dissertation, faculty members can point out a wealth of avenues their own research has suggested. Furthermore, from the pool of equipment such an operation develops, the graduate student may assemble his needed apparatus in a great deal less than the 6 months it often takes to bring together the facilities needed for the research he is often expected to finish in 1 yr.

The Professional Yardstick.—To work out its problems of financial strength and student enrollment, any institution offering graduate degrees in sanitary engineering now needs a yardstick by which both the institution and the student may judge the adequacy of its program. At best the small total number of graduate students enrolled makes the sanitary engineering program an expensive one. How expensive can not be estimated by any institution proposing to launch such a program unless a way can be found to judge how nearly it must imitate the leading schools in order to maintain a sanitary engineering program which is professionally acceptable. Hence, there is no basis for an administration to decide whether sanitary engineering is a feasible and justifiable part of its over-all engineering program.

One answer to the yardstick dilemma might be accreditation of sanitary engineering at the M.S. level by the Engineers' Council for Professional Development (ECPD) under its policy of so evaluating the first degree given in any field. Harvard University and the University of California have already sought and received such accreditation on a three-year basis. While this action has opened up problems of policy concerning graduate accreditation in general and brought up questions beyond the scope of this paper, there is reason to believe that it is a step in the right direction.

As long as sanitary engineering was essentially an option in an accredited department of civil engineering, even though the option itself was not especially involved in the accreditation, each institution had some idea of the acceptability of its product. Graduation from an accredited civil engineering curriculum told the prospective employer that the applicant had at least the minimum qualifications expected by the engineering profession. That he had pursued optional work in sanitary engineering served to polarize in the applicant's favor the employer seeking such competence. Educational institutions and employers alike recognized that some schools offered higher grade programs than others, but accreditation reduced the need for the poorest program to strive to equal the best.

The smaller or less well organized departments of sanitary engineering have tended to oppose accreditation. Some have felt that it might tend to impose unattainable or unacceptable goals, or serve to render them ineligible for traineeships and other outside financial aid. On the other hand, it may be argued that establishment of some minimum requirement would assist the department head in getting a program under way, for it would enable his administrative superiors to estimate the limits of expense involved. Furthermore the granting of support, especially public funds, from outside agencies must inevitably be decided on the basis of the judgement of the grantor's staff and advisory committees. One basis for such judgement will inevitably be the competence of the staff, and the nature of the facilities of the institution seeking support. Whether suitable criteria must be developed by the agency dispersing funds or are those established by the sanitary engineering profession itself, becomes the question.

The groundwork for the resolution of this question was, however, laid at Cambridge, Massachusetts in June 1960 at a conference[2] on Graduate Education of Sanitary Engineers sponsored by the American Sanitary Engineers Intersociety Board (ASEIB) in co-operation with NSF, Harvard University, and Massachusetts Institute of Technology (MIT). On that occasion, it was recommended by more than a hundred educational leaders in the field that ASEIB take a strong position favoring accreditation of Master's programs in sanitary engineering and related disciplines; support ECPD in such accreditation; and, in the event ECPD elects not to continue such accreditation, undertake to develop its own accreditation program.

In summary it may be said that changes in objectives of undergraduate engineering education, together with an expanded range of concern with man's environment, has caused sanitary engineering to leave the undergraduate scene for a new place in the graduate field. In general the larger school is favored both because of its innately greater financial resources and of the opportunities it can provide graduate students through the vast research pro-

[2] "Report on Study Conference on the Graduate Education of Sanitary Engineers," ASEIB, Cambridge, Massachusetts, June 27-29, 1960.

gram its varied staff attracts. In contrast, the formerly successful undergraduate school must now attempt to meet the standards set by the larger graduate institution, perhaps with but one or two staff members to carry some half dozen special aspects of the sanitary engineering program.

Thus staff limitations, research opportunities, and increased student instruction costs conspire against the small or predominantly undergraduate school which must now operate at the graduate level. Under such circumstances the graduate student tends to seek the best known school which can offer him a suitable financial arrangement.

Of some departments it has been said with a degree of truth that the number of staff exceeds the number of graduate students. This, however, is not an unmitigated evil; for such staffs thrive on research. Research develops and improves the competence of the professor. This, in turn, enhances the reputation of both the professor and his institution and attracts graduate students. Furthermore, it provides opportunity both for the independent investigative work required of the advanced student, and for his partial financial support. Thus, a large staff of highly productive and competent instructors begets the research which supports the staff and the graduate students, while providing opportunity for each to develop. The results are of singular importance. To the profession it means that by moving into the graduate years, sanitary engineering has been given both a scope and quality formerly unattainable; it has come of age. To the big and comparatively prosperous departments, it has meant increased opportunity to educate men and to grow in reputation. But to the small institution which formerly did a commendable job at the undergraduate level, it has meant an overworked and sometimes frustrated staff, an intensified competition for students, a struggle to maintain standards, and often an expensive educational burden. The profession of sanitary engineering has already begun to take a hard look at itself and to seek some new and significant answers to questions concerning accreditation, availability of graduate students, and the nature of the graduate program.

CONCLUSIONS

From the factors discussed and their obvious implications, it is possible to draw a number of major conclusions concerning the current status and the future of sanitary engineering education. These include the following:

1. The trend toward broadening undergraduate engineering education through increased concern with humanities, basic science, and engineering science, which began at the close of World War II, has made it essentially impossible for a 4-yr curriculum in civil engineering to retain any degree of undergraduate specialization. Consequently, sanitary engineering has become a graduate specialty.

2. Movement of sanitary engineering from the undergraduate to the graduate school has had the effect of removing the "umbrella" of ECPD accreditation under which it formerly stood as an aspect of accredited civil engineering. As a result, the predominantly undergraduate institution finds it hard to judge the level of investment in staff, facilities, and course offerings necessary to make it professionally acceptable.

3. Accreditation of sanitary engineering and related programs at the M.S. level will be encouraged as a result of recommendations of an ASEIB-sponsored conference of sanitary engineering leaders held in June 1960.

ECPD accreditation of such programs involves only Harvard University and the University of California (as of March 1961).

4. Few engineering schools which successfully offered undergraduate specialization are likely to be content with general programs alone. Therefore, sanitary engineering may be expected to appear in the graduate offerings of numerous institutions, especially at the Master's level.

5. The cost of graduate education is such that financial aid to the graduate student either through scholarships, traineeships, grants, or employment is today almost universally necessary.

6. Federal and other financial support of graduate students and facilities in sanitary engineering has not attracted students in the numbers for which the program was intended. It has, however, encouraged many institutions to offer graduate programs. The result is that 57 institutions competed for 413 students in 1960.

7. There is a tendency for graduate students to seek the few major institutions whose financial resources and extensive research programs can support a large and varied staff of specialists in the many aspects of sanitary engineering, as well as offering assistance to the students themselves.

8. There is no reason to expect that sanitary engineering as a profession is likely to attract enough students to justify the multiplicity of programs that are to be offered. More likely, a large number of accredited programs will become available to meet the specialty needs of a relatively small total of M.S. graduates each year. Meanwhile, the emphasis on the doctorate as a professional qualification will grow, with a few institutions drawing their advanced students from the graduates of the many, as well as from their own, M.S. programs.

9. The sanitary engineering profession should, and is beginning to, take an active interest in problems of recruitment of students and context of programs on which the future of the profession depends.

10. Sanitary engineering education has at its highest level attained a scope and quality worthy of a true profession as a result of moving into the graduate years.

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FISHERIES STATISTICS IN EVALUATING CLAIMS OF POLLUTION[a]

By Roger Tollefson[1]

SYNOPSIS

Used cautiously, fisheries statistics can be invaluable to the sanitary engineer in evaluating claims that waste discharges are responsible for declining or fluctuating fisheries resources. After describing types of data encountered (catch, catch per unit of effort, actual populations, time of occurrence), proper and improper uses of statistics are shown in nine illustrations.

INTRODUCTION

Fisheries statistics is not a new subject; anyone who is connected in any way with a fishery resource is familiar with them. Due to this common familiarity with fisheries statistics, there is a danger of oversimplification in their use when applying them to specific problems—as, for example, pollution versus fisheries. Erroneous conclusions may be drawn either because of the inadvertent misuse of statistical principles or because of inadequate treatment.

Nevertheless, these statistics are of vital importance to the engineering profession as well as to the biologists. The engineer or administrator who must make project decisions of an ancillary nature will find statistics an indispensible tool in determining their fullest significance within the context of

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[a] Presented at the June 1960 ASCE Convention in Reno, Nevada.

[1] Cons. Biologist, Toledo, Ore.

the total problem. They also provide an objective method for separating fact from mere theory.

HISTORICAL DEVELOPMENT

Before discussing the use of fisheries statistics as an applied tool, it may be well to briefly review their historical development. Such a review is especially important for in this particular field the analyst is frequently dealing with an accumulation of data that have been basically unchanged since they were first acquired. Their use, of course, is governed by the same limitations that were present at the time the data were gathered.

The history of fisheries statistics, especially in the western half of the United States, had it inception in the period between 1850 and 1900—an era of intense scientific curiosity about all aspects of our natural resources. Born in this era of naturalism, it is understandable that many of these original fisheries statistics were compiled solely to supplement or to illustrate the natural history studies of the time, and must be viewed with this qualification in mind.

It was around the turn of the twentieth century, when governmental agencies began levying license and poundage taxes, that the commercial fisheries statistics began to assume a dominant importance. It is quite likely, however, that the statistics gathered for such tax purposes reflected the struggle between the government to collect and the public to evade taxes. Their reliability and use must, therefore, be carefully assessed with this limitation in mind.

A logical evolutionary development following taxation would seem to be a clamor from the public to "get something for its money." This public demand eventually gave rise to the management of fisheries resources. A similar sequence in development occurred with respect to the sports fisheries. With management, truly reliable figures (accurate in respect to biological factors as well as economic fishery statistics factors) first appeared.

The simplest and most commonly used form of fishery statistics is the total catch of fish per unit of time, usually per year. In applying such data to specific problems, such as pollution, care must be taken, that the figures do, in fact, represent the particular areas under study. Consequently, the first objective should be to limit the statistics to the particular area in question. It is difficult, of course, to set any hard and fast rules of procedure for circumscribing problem areas. This entails a clear understanding of the problem and a proper appreciation of all of its various aspects.

Assuming the successful limiting of statistics to a well defined pollution problem area and a resultant derivation of pertinent facts, there now remains the determination of their significance. In determining the significance of catch data in pollution problem areas, the analyst is ultimately dependent on biological explanations for any population changes. Lacking such information he must resort to the expedience of comparing such data with the data from other, similar areas or to larger, overall areas. Because no two areas are exactly alike, considerable discretion must be exercised in formulating conclusions.

Establishing the parameters for pollution problem areas involves not only the dimension of an adequate geographical base, but also the dimension of an adequate time period. This is important because definite trends must be distinguished from normal cyclic changes.

In addition to statistics involving catches, a number of other forms of statistics are sometimes available. One of these would be data on actual populations of fish in a lake, in a given stretch of stream, or for some given run of fish. This gives not only the number of fish that may have been caught at some time, but what is much more important, the number of fish which escaped. Properly handled, such statistics will provide a much more accurate picture of biological populations. It surmounts the handicap of catch data alone, that presupposes not only the accuracy of the data as presented, but also a uniformity of fishing effort and fishing success.

Another statistical expression, sometimes available, is the so-called "catch per unit of effort." This is basically a catch or landing record, but is weighted in respect to the number of fishermen or to the amount of effort expended in fishing. It is generally considered to be a better biological index of populations than catch alone. The accuracy of catch per unit of effort data depends, however, on the accuracy of assessing the magnitude of effort actually expended. The greatest significance can usually be derived from the two extremes of fishing effort where there has been a pronounced change in fishing intensity throughout the time period involved. It is apparent that a catch per unit of effort that is based on inadequate determinations of effort may be very misleading and worse than no data at all.

There is a specialized type of fishery statistic relating to certain migratory fish, that is to their time of occurrence and to their relative abundance in a given area. This applied particularly to anadramous species, or fish having some regular migration pattern, usually related to spawning activities. Such data can be of great importance when available and where pertinent.

EXAMPLES

In some of the subsequent examples certain liberties have been taken with the original source reports and with the data for better illustration, without altering their contextual significance.

Fig. 1(a) shows the commercial Chinook salmon landings for Oregon as the total catch for all areas and all gear of the state, along with the total catch of Chinook from the coastal rivers only.[2] Fig. 1(b) depicts the commercial landings for two of these individual coastal rivers, the Nehalem and the Siletz. The necessity for limiting the scope of the statistics to be used becomes apparent if we were to assume a hypothetical pollutional problem on either the Nehalem or the Siletz river. Entirely different interpretations could be placed on the results of such a study depending on whether the data were evaluated according to their local context only, or according to other, somewhat similar areas, or even to a broad geographical area.

Fig. 2 illustrates a situation with winter steelhead where it was necessary to go to a broad base for evaluation of pertinent local data.[3] Various people in recent years have maintained that a pollution problem exists on the mouth of the Chambers Creek in Washington, on which the state has located its most important steelhead hatchery.[4] Certain deviations and an apparent decline in

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[2] "A Summary of Fishery Statistics of the Pacific Coast," by Roger Tollefson, Laurie Leonard, Richard Peterson, Norman Chamberlain, and Jean Buyes, December, 1959, 182 pp.

[3] "Winter Steelhead - Washington - Fluctuations and Trends," by Roger Tollefson, presented at the March 12, 1960, Washington State Sportsmen's Council Meeting, 17 pp.

[4] "An Investigation of Water Quality Conditions in Chambers Creek Estuary," Tech. Bulletin 24, Wash. Pollution Control Comm., 1958, 79 pp.

adult returns to the hatchery have been pointed to as proofs of existing pollution. In Fig. 2, have been plotted (as a percentage deviation from the mean basis) the returns to Chambers Creek that do indicate a general decline. However, the total Washington State winter steelhead sport catch for all rivers of the state are also plotted in Fig. 2 (no commercial fishery exists

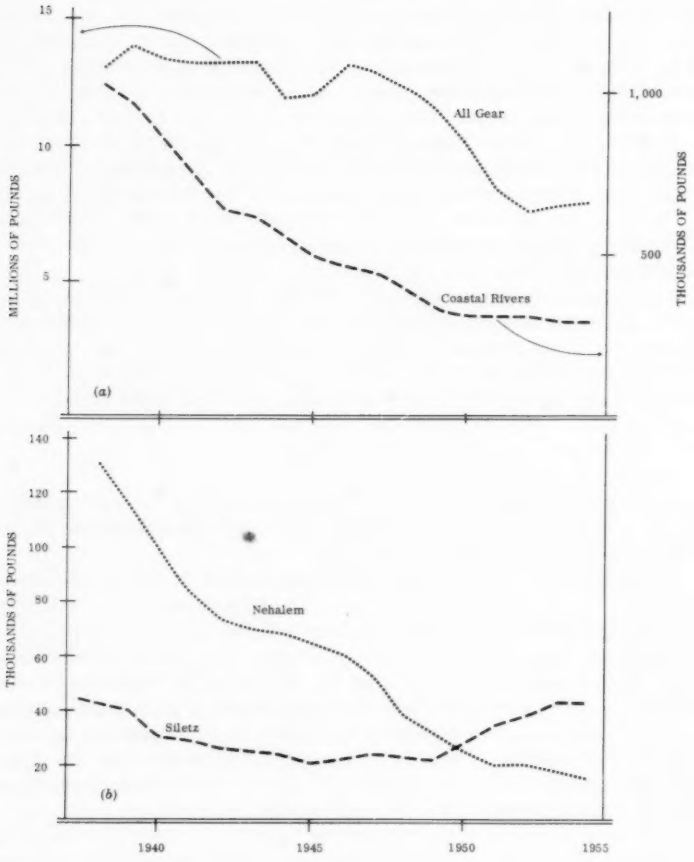

FIG. 1.—CHINOOK SALMON LANDINGS IN OREGON

here with the exception of the Columbia). The striking similarity, if not identical character, of these comparative returns certainly does not indicate the existence of any pollution problem on this stream.

Fig. 3 is presented to show the danger in the use of incomplete statistics. In Fig. 3(a) is plotted the "major" Olympia oyster production for Puget Sound,

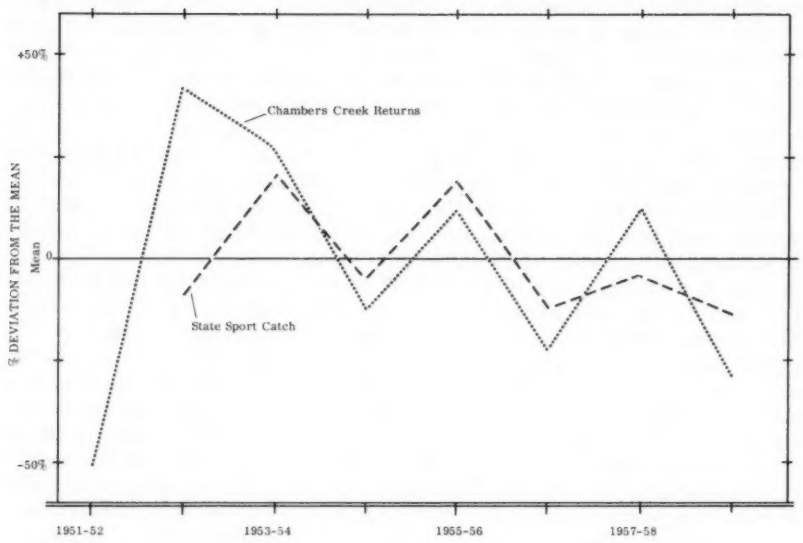

FIG. 2.—WASHINGTON WINTER STEELHEAD, BROODSTOCK RETURNS AND CATCHES

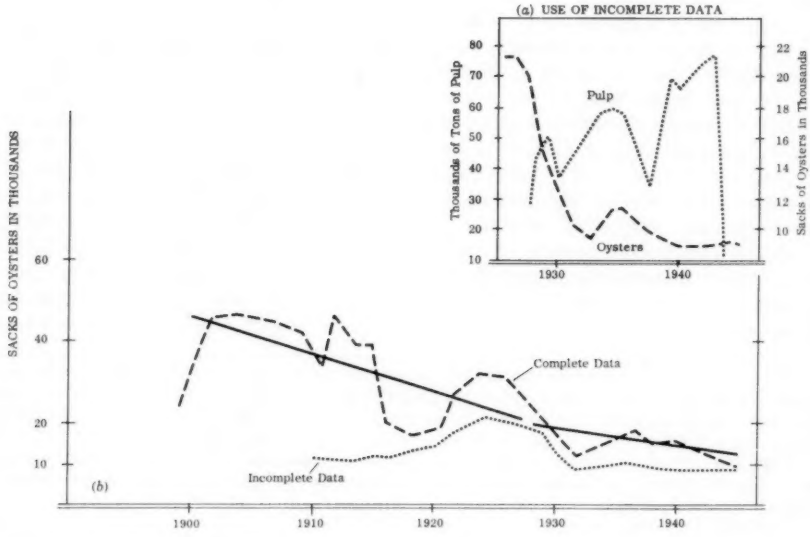

FIG. 3.—OLYMPIA OYSTER PRODUCTION IN PUGET SOUND

Wash., against the production of an adjacent pulp mill as also shown.[5] This particular sketch was used as support for the final conclusion that pollution had been the cause of oyster decline shown. Fig. 3(b) depicts the complete production statistics of Olympia oysters for this area for the time covered in the top sketch as well as the years before this time period. Obviously, the reported "major" production listed was far from complete. Computed regression lines for the period both preceding and following the installation of the pulp mill (1927) in question are also shown.[6] It will be seen that not only does the decline referred to start long before the installation of the mill, but that the rate of decline actually decreased following the installation of the mill. It is readily apparent how a conclusion may be influenced by the use of incomplete statistics as implied in the upper portion of the figure.

In Fig. 4, examples are shown of both population statistics and catch per unit of effort. Fig. 4(a) shows the total run or population of spring Chinook salmon in the lower Willamette River during the time period indicated.[7] In this particular case, the presence of fishways permitted a fairly exact determination of the total run. In Fig. 4(b) we find the total catch of fish out of this population along with catch per unit of effort. It will be seen that the trends and magnitudes are the same for all three expressions in this case, although some noteworthy differences are evident. It will, also, be seen that the magnitude of fluctuations for both catch and catch per unit of effort are considerably less than that expressed by the total population. For some years the catch statistics bear the closest relation to the total population while in others the catch per unit of effort is perhaps more accurate. In this particular example, where degree of effort was roughly comparable throughout the time period shown, there is little difference in the results between the two statistics, each one serving as a usable and valuable tool. Had extreme changes occurred in fishing intensity during the period, the catch per unit of effort data would undoubtedly have been the more accurate.

Fig. 5 is used as an example of the seasonal or timing aspect of statistics from a pollution standpoint as depicted by the number of downstream migrants caught per seine haul in the Willamette River below a suspected pollution area.[8] It is seen (as concluded by Donald L. McKernan and Chester R. Mattson) that a seasonal drop in dissolved oxygen corresponding with the time of downstream migration of the fingerlings created a pollution problem. From the standpoint of a seasonally present species, it is obviously necessary to utilize the seasonal statistics for all biological and physical factors involved.

In the Pacific Northwest, as in most sections of the United States, pollution is a highly controversial subject. Because the pulp and paper industry comprises one of the largest single users of water for waste-disposal purposes, it is especially subject to criticism. In view of this, and in order to obtain

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[5] "An Investigation of the Decline of the Native Oyster Industry of the State of Washington, with Special References to the Effects of Sulfite Pulp Mill Waste on the Olympia Oyster (Ostren lurida)," by Donald L. McKernan, Vance Tarter, and Roger Tollefson, Tech. Bulletin No. 49-A, State Dept. of Fisheries of Wash., April, 1949, pp. 117-165.

[6] Letter report on "Decline in Olympia Oyster Production - Puget Sound, 1897-1958," by Vinton W. Bacon, to Board of Scientific Consultants to Wash. Pollution Control Comm., August 26, 1959, 3 pp.

[7] Annual Reports, Oregon Game Comm., 1946-1957.

[8] "Observations on Pulp and Paper Effluents and the Probable Effects of This Pollutant on the Fisheries Resources of the Willamette River in Oregon," by Donald L. McKernan and Chester R. Mattson, Fish Comm. Research Briefs, Vol. III, No. 1, September, 1950, pp. 14-21.

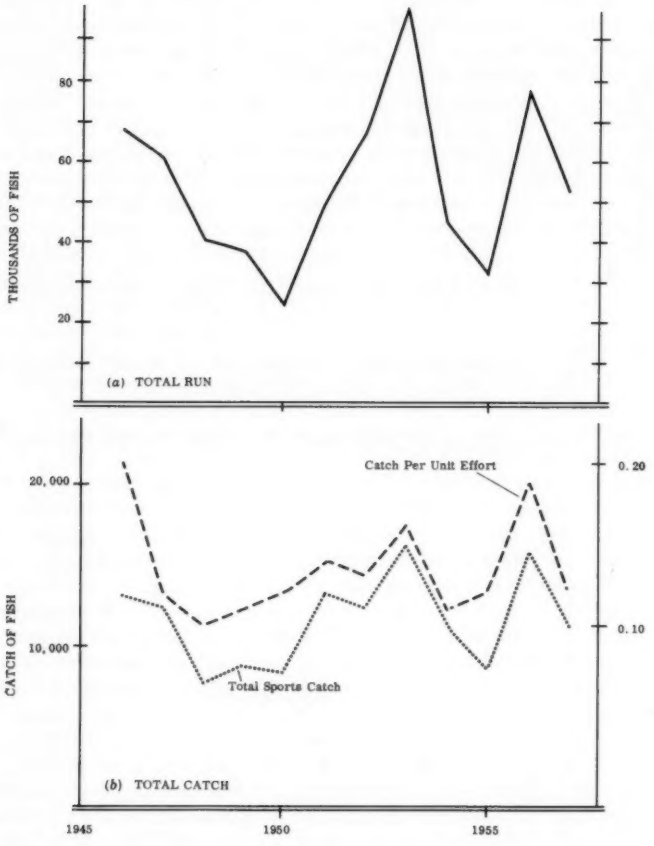

FIG. 4.—SPRING CHINOOK IN LOWER WILLAMETTE

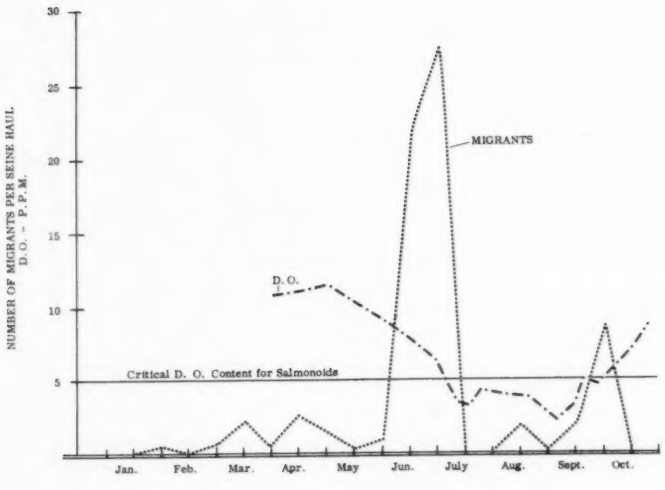

FIG. 5.—DOWNSTREAM MIGRANTS, WILLAMETTE RIVER, 1949

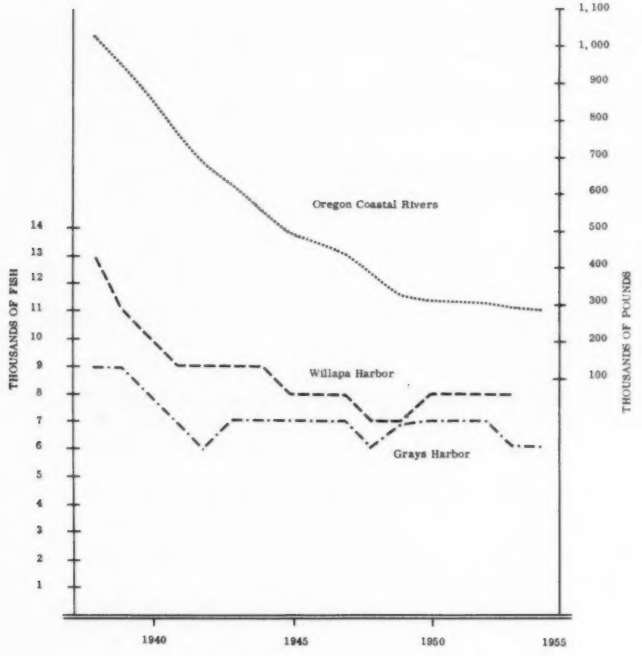

FIG. 6.—CHINOOK SALMON, "INSIDE" RIVER LANDINGS

supplementary background information, the Northwest Pulp and Paper Assoc. commissioned a study or compilation of fishery statistics pertinent to their area,[2] from which several examples of application will be drawn.

For example, in Grays Harbor, Wash. pulp mill pollution has allegedly caused declines in the fish runs of that area. On various occasions, data have been presented to substantiate this allegation.[9] Here is another instance of the necessity for comparing correctly treated although limited, data to other and broader areas in order to elucidate their real significance. Fig. 6, a graphic illustration of the "inside" river landings for Grays Harbor, does show a decline from earlier years for this area as so frequently contended. However, when one compares the corresponding catches for Willapa Harbor, an immediately neighboring estuary possessing a similar watershed but devoid of any industrial pollution, one finds a similar decline which, in fact, is even greater than that in Grays Harbor. Also shown in Fig. 6 are the corresponding total landings for the Oregon coastal rivers, given as the composite results from twelve different rivers of similar type and watershed, none of which is considered to have a serious pollution problem, indeed in most of which pollution is no problem at all. Yet the same pattern of decline is found as evidenced at Grays Harbor and again on a greater scale. As already noted all of the data pertinent to a specific study area may be available, but in order for conclusions to be valid, these limited data must be compared to other and broader areas.

In Fig. 1 it was seen that in the case of the Oregon data the use of the local coastal river catches alone would be inaccurate in assessing the true trends of the Chinook salmon. The evaluator must incorporate not only the Columbia River catches as well, but what is more important, the ocean troll fishery which has been expanding greatly in recent years. Although no attempts will be made herein to evaluate the various components of this off-shore fishery, such an evaluation would, of course, be a necessary part of any final careful analysis. The sports catch is another important aspect requiring consideration in any final analysis. In the case of the Columbia River, for example, the sports catch of Chinook salmon is in excess of 20% of the toal river caught fish (50% in the case of silver salmon). A fishery of this magnitude cannot be disregarded, but must be included in the final totals.

In Fig. 7, the total Chinook landings (commercial) are plotted for Alaska, Washington, and Oregon as another comparison to the "inside" river data previously shown. Even with the inclusion of the offshore fishery, it is still evident that at least some decline exists in every major area regardless of the presence, or degree, or absence of industrial development. Actually, Washington, possessing the greatest industrial development and receiving the most complaints, shows the greatest stability of the three areas. Analyzing the situation on broad scale, these statistics clearly demonstrate that any practical effects of pollution must be secondary, if existing at all.

A decline in the Puget Sound crab landings, as shown in Fig. 8(a), has also been used as evidence proving adverse pollution effects in certain areas of the Sound. However, when these landings are differentiated by areas into "possibly polluted" industrial groups and "known to be unpolluted" groups, and so plotted, as shown in Fig. 8(b), no significant difference is found. It would seem more realistic to compare the over-all decline in this "inside" fishery with

[9] "A Reinvestigation of Pollution in Grays Harbor," Tech. Bulletin No. 21, Wash. Pollution Control Comm., 1956, 1957, 52 pp.

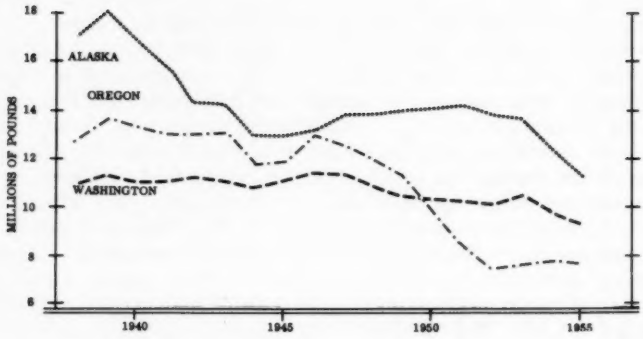

FIG. 7.—CHINOOK SALMON, TOTAL LANDINGS BY STATES

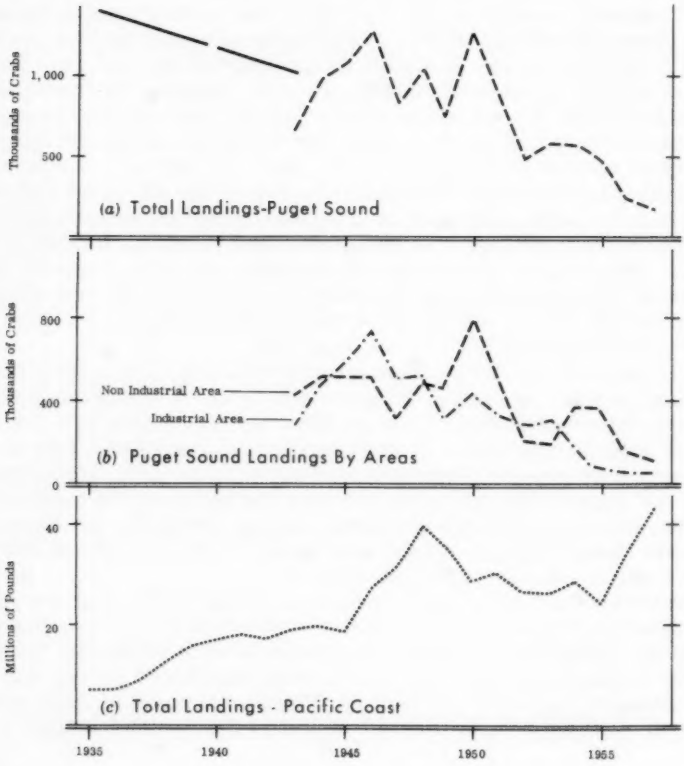

FIG. 8.—CRAB LANDINGS

the expansion of the off-shore fishery as represented in Fig. 8(c). This becomes quite evident when certain known economic factors are considered, especially the cost price ratio differences that exist between the "inside" and off-shore fisheries. The latter, operating at greater efficiency and with larger catches, enjoys a more favorable position for meeting price competition. This same type of situation can be shown to occur in virtually every bay crab fishery on the Coast.

The statistics herein can also be used to compare population trends in species of fish other than the one of direct concern where additional, sup-

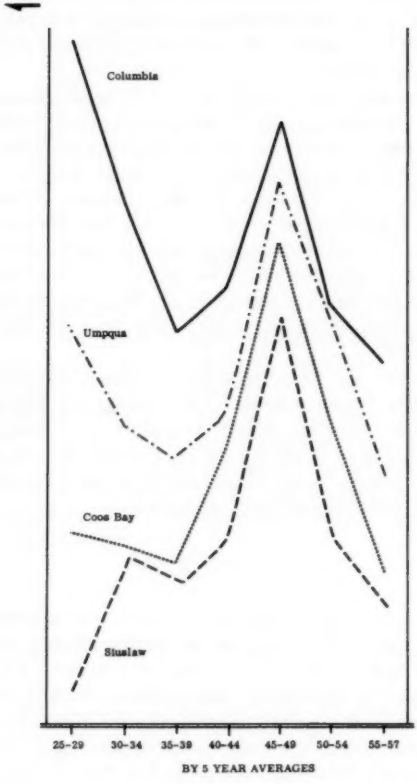

FIG. 9.—SHAD LANDINGS, TRENDS IN COASTAL RIVERS

porting evidence is desired. Should pollution be a primary cause of the observed decline in Chinook salmon within the Columbia River, for example, it would be logical to assume that other species of fish should be similarly affected.[8] To examine this point, shad landings are shown in Fig. 9 for all major shad streams of the Northwest. It is found that although fluctuations are present, there is no definite trend indicating a decline. It will be noted, more-

over, that although the Columbia River is the only river receiving industrial wastes, identical patterns exist in all of the shad streams. Examination of the data for other species leads to the same general conclusion. In the case of smelt, for example, extreme fluctuations are found occurring throughout its history, with no correlation with industry. In the case of white sturgeon, variations exist throughout a more or less stable fishery. This list can be expanded by species, time, and area for a more exact analysis of the overall situation.

In short, detailed local statistics are at times available, and have, on occasion, been used to support contentions of the existence of pollutional problems. Full use and analysis of all the statistics available, however, generally leads to the conclusions that in terms of practical importance, pollution is one of the least troublesome problems facing our fisheries.

One must be especially careful in the statistical (mathematical) analysis of fisheries data if attempting to draw correlations between declines and possible causes. Fishery resources, in general, are sensitive to many changes in their environment. Almost any activity of man, past or present, affects a given fishery, usually in an adverse manner. Indeed, it would seem that the history of a fishery resource reflects inversely the advances of civilization. Pollution is but one of the many complex factors associated with our dynamic civilization that affect a fishery, and it would be an over-simplification indeed to single it out and to establish a statistically significant correlation between it and a fishery decline, when in reality one may not have had any bearing whatsoever on the other.

Many such cases can be found in the statistical compilation prepared for the Northwest Pulp and Paper Assoc.[2] The California Pismo clam fishery is an outstanding example where a marked decline can be correlated with what might be termed the general advances of civilization minus any industrial developments. The original Washington shrimp fishery and the pilchard or sardine fishery are other outstanding examples.

CONCLUSIONS

It is seen that the fishery statistics available for specific pollution problems are often, by themselves, inadequate or unreliable and for their fullest significance must be appraised within broader contexts. The important point, however, is that fishery statistics do provide a series of approaches for evaluating possible or contended pollution problems. We are faced with mounting biological data indicating the older, conventional, chemical water quality criteria to be inadequate of demonstrating, by itself, the existence or non-existence of pollution especially in respect to its biological implications. It would further seem that with the rapidly growing understanding of the concept of multiple water use, pollution will need to be more broadly defined as unnatural discharges that adversely affect man's total use of water, rather than only some individual aspect of it. From this point of view fisheries statistics provide one of the best means for measuring the practical effects of particular water usages on the total water resource.

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Proceedings of the American Society of Civil Engineers

FILTRATION USING RADIOACTIVE ALGAE

By Kenneth J. Ives,[1] M. ASCE

SYNOPSIS

The modern scientific techniques of radioactive labelling and automatic digital computation were used in an experimental study of a new theory of rapid filtration. The algae Chlorella and Scenedesmus were made radioactive and suspensions of these algae were filtered through a sand column. The distributions of the algae deposited in the filter pores were measured with a scintillation counter, and the resulting data was used to check the validity of the theory. The computer computed information on changes in water quality and head loss in the filter. This information was compared with experimental results and provided information on filter operation that could be used for rational filter design.

INTRODUCTION

Engineers concerned with the design or operation of rapid filters are aware, in general, of what to expect from the performance of such filters. However, there has been no adequate mathematical statement of the scientific principles expressing filter performance until recently, when the writer[2] discussed his own theory and those of D. M. Mints[3] and V. and S. Mackrle.[4] If these state-

Note.—Discussion open until October 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. SA 3, May, 1961.

[1] Lecturer, Dept. of Civ. Engrg., University Coll., London, England.

[2] "Rational Design of Filters," by K. J. Ives, Proceedings, Inst. of Civ. Engrs., Vol. 16, 1960, p. 189.

[3] "Investigation of the Process of the Filtration of Suspensions," by D. M. Mints, Zhurnal Prikladnoi Chimij (Akademii Nauk SSSR), Vol. 33, 1960, p. 304.

[4] "Adhesion in Filters," by V. Mackrle and S. Mackrle, Rozpravy Ceskoslov, akad, ved., Rada tech. ved., Vol. 69, 1959, p. 2.

ments are verified experimentally and tested in practice they can be used as a basis for rational filter design, prediction of performance and comparison between filters.

The experiments are described herein, that were undertaken to test the hypotheses advanced in the theory, and to test the rationale of determining design parameters.

Notation.—The letter symbols adopted for use in this paper are defined where they first appear, in the illustrations or in the text, and are arranged alphabetically, for convenience of reference, in the Appendix.

FILTER OPERATION

When turbid water is filtered the amount of turbidity diminishes as the water passes through the filter, resulting in a more or less clear filtrate. As the filter run proceeds the bed becomes clogged, and the filtrate at first improves. Later it steadily deteriorates, and ultimately, if the filter can be maintained with sufficient pressure, the filtrate becomes as turbid as the influent. The clogging of the filter is worst nearest the surface and as the run proceeds, the clogging gradually works down through the bed. The head loss depends on the degree of clogging and most of the pressure drop is in the upper layers of the filter. However, as the clogging extends down, the lower layers contribute more to the head loss.

It has also been demonstrated that a deeper filter will produce a clearer filtrate, heavier inflow concentrations will produce more rapid clogging, and more rapid filtration will carry suspended particles through. Smaller filter grains are known to be more effective for filtration, and more angular media (for example, anthracite) at the same porosity, to give improved filtrates. Finer suspended particles are known to be less amenable to filtration and denser particles are found to be more readily removed.

All of these well-known characteristics have to be given a rational basis, and are in fact inherent in the theoretical exposition which follows.

FILTRATION THEORY

The theory of filter behavior was developed on the following three principal assumptions:

1. The removal of suspended material from water by a filter layer is proportional to the quantity of suspended material present in the water.
2. The removal characteristic of the filter depends on the surface available on the filter grains, on the tortuosity of flow within the pores, and on the interstitial velocity.
3. The principal force operating to remove suspended particles from the flow stream lines is gravitational, although adsorptive forces become dominant when a particle reaches a grain surface.

These assumptions led to the development of an equation relating the changes in concentration through the depth of a filter with a parameter of the clean filter and the quantity of deposit in the pores.

$$-\frac{\partial C}{\partial L} = \left(\lambda_i + c\,\sigma - \frac{\phi\,\sigma^2}{f - \sigma}\right) C \quad \ldots\ldots\ldots\ldots \quad (1)$$

Eq. 1 states that the removal of suspension (concentration C) at any depth (L) is proportional to the concentration, the proportionality depending on the clean filter coefficient (λ_i) and its subsequent modification by the quantity of deposit per unit filter volume (specific deposit σ). The value f is the clean filter porosity, and c and ϕ are constants.

The concentration change in the flow is equated to the accumulation of deposit in the filter by the continuity equation:

$$-\delta C\, Q\, \delta t = \delta\sigma\, A\, \delta L \quad \ldots\ldots\ldots\ldots\ldots (2a)$$

in which δC is the change in concentration in time δt, flowing at a rate of Q into a layer of area A and thickness δL, in which the specific deposit increases by $\delta\sigma$. In differential form putting approach velocity v = Q/A,

$$-v\,\frac{\partial C}{\partial L} = \frac{\partial \sigma}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2b)$$

The solution of the linked partial differential Eqs. 1 and 2(b) will give the variation in concentration in the flow at any depth during the time of filter operation, and will also give the quantity of accumulated deposit in any filter layer at any time during filter operation. With the latter known it is possible to obtain the head loss in any layer at any time from the equation:

$$\int_{H_i}^{H} dH = p \int_0^{\sigma} \left(\lambda_i + c\,\sigma - \frac{\phi\,\sigma^2}{f - \sigma}\right) d\sigma \quad \ldots\ldots\ldots (3)$$

and

$$H = p\left[\left(\lambda_i + \phi\, f\right)\sigma + \frac{c + \phi}{2}\,\sigma^2 + \phi\, f^2 \log_e \frac{f - \sigma}{f}\right] + H_i \quad \ldots (4)$$

in which H_i and H are the initial and final losses of head (water gage) per unit depth containing accumulated specific deposit σ, and in which p is a head loss coefficient. The total head loss to any depth L will be the sum of the head losses through the various layers.

$$H_L = \int_0^L H\, dL = \int_0^L p\left[\left(\lambda_i + \phi\, f\right)\sigma + \frac{c + \phi}{2}\,\sigma^2 + \phi\, f^2 \log_e \frac{f - \sigma}{f}\right] dL + H_i L \quad \ldots (5)$$

The term H_i is the clean filter head loss per unit depth that can be obtained from Kozeny's or Rose's well established equations.

Eqs. 1, 2(b) and 5 have not been solved analytically, but numerical solutions have been obtained on automatic digital computers.[5] Such solutions enable the behavior of the filter to be predicted for any depth and for any time of operation. It is necessary to obtain values for the filter coefficients λ_i, c, ϕ, and p, and of the operating approach velocity v and initial porosity f. The determination of the latter two are standard procedures, but the other coeffi-

5 "Simulation of Filtration on an Electronic Digital Computer," by K. J. Ives, Journal, Amer. Water Works Assoc., Vol. 52, 1960, p. 933.

cients are unfamiliar and their empirical determination will be described subsequently.

EXPERIMENTAL STUDY

In order to test the theory, experimental conditions that were close to ideal were required. These ideal conditions were:

1. Uniform suspension remaining constant with time, flowing into the filter;
2. Suspension particles unisize and of definable geometry;
3. Uniform size of filter media; and
4. Constant temperature and constant flow rate.

Two species of artificially cultured algae, Chlorella sp. and Scenedesmus sp. were used as the suspensions in tap water at laboratory temperature, stirred continuously to maintain uniformity. The filter column was a 2 3/4-in.-diameter cylinder containing a 24 in. depth of sand. The sand size was defined by two adjacent sizes in the Tyler (U.S.) sieve series. Flow rate was manually adjusted with a needle valve, with reference to a rotameter.

It was required to measure the quantity of material clogging the pores in each layer of the filter and a radioactive technique was adopted. By making the algae radioactive their accumulation in the filter pores could be measured with a detector mounted externally to the filter column (Fig. 1). These techniques are described in detail elsewhere.[6] In essence they comprised growing the algae in an inorganic nutrient medium (to suppress bacterial and fungal growth) containing the radio-isotope cesium - 137. The algal culture, when developed, was removed from the culture medium, given several washings with distilled water and then dispersed in tap water ready for filtration. The scintillation counter for detecting γ- radiation from the algae was mounted on a rack so that it could be set with a collimating slit 1 cm high through its lead shield, opposite any layer of the filter. The scintillation counter was previously calibrated so that its reading could be converted to the equivalent number of algal cells occupying the layer opposite the collimating slit. The counter traversed the filter from the sand surface through its depth every half-hour during the filter run. A similar technique has been described by D. R. Stanley,[7] in which filtration was halted at intervals and the filter column removed and traversed against a fixed radiation detector.

EXPERIMENTAL RESULTS AND DATA ANALYSIS

From the scintillation counter readings and calibrations the quantity of algae deposited in each layer was obtained for various times during the filter run, and graphs such as Fig. 2 resulted. Also from the data typical graphs of specific deposit against time could be plotted as shown in Fig. 3. Such graphs are the key to obtaining the characteristic parameters λ_i, c and ϕ. By putting

$$\lambda = \lambda_i + c\,\sigma - \frac{\phi\,\sigma^2}{f - \sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

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6 "Cesium 137 Labelled Algae for Filtration Studies," by K. J. Ives, International Journal of Applied Radiation and Isotopes, Vol. 9, 1960, p. 49.

7 "Sand Filtration Studies with Radiotracers," by D. R. Stanley, Proceedings, ASCE, Vol. 81, Sep. No. 592, 1955.

and substituting Eq. 6 in Eq. 1, and combining Eq. 2(b)

$$\frac{1}{v}\frac{\partial \sigma}{\partial t} = \lambda C \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

and

$$\lambda = \frac{1}{C v}\frac{\partial \sigma}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

For the surface layer of the filter $C = C_i$ (the inflow concentration), and the slope of the σ against t graph gives $\partial\sigma/\partial t$, hence λ can be computed for various σ values. Accordingly, a graph can be plotted of λ against σ, as

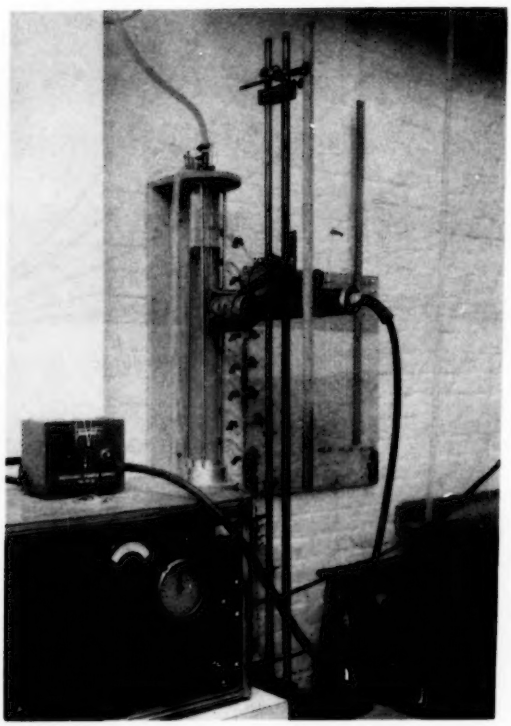

FIG. 1.—FILTER COLUMN WITH RADIATION DETECTOR AND COUNTER

shown in Fig. 4. This is in accordance with the theoretical Eq. 6, and the intercept at $\sigma = 0$ gives λ_i, with slope at this point equal to c. The value of ϕ is obtained from a transposition of Eq. 6.

$$\phi = \frac{(\lambda_i + c\,\sigma - \lambda)(f - \sigma)}{\sigma^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Manometer readings taken at intervals during the filter run, for various filter layers enabled head loss to be plotted against specific deposit as shown in Fig. 5. The slope of this graph gives $dH/d\sigma$. Consideration of Eq. 3 gives

$$\frac{dH}{d\sigma} = p\,\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

So, if $dH/d\sigma$ is plotted against λ, as shown on Fig. 6, the slope of the graph gives p.

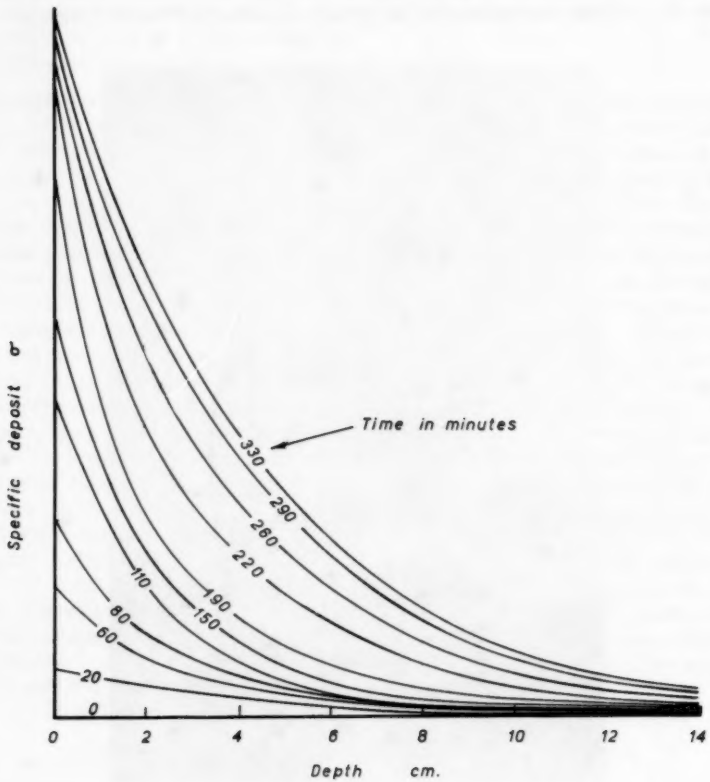

FIG. 2.—EMPIRICAL DISTRIBUTIONS OF DEPOSITED MATERIAL IN THE TOP LAYERS OF A FILTER

Values of these parameters for the two algal suspensions and various filtration conditions are given in Table 1.

With the exception of run No. 2A which appears to have anomalous results in relation to the rest of the table (the cause of this was not determined), certain interesting facts appear from inspection of Table 1.

1. For a given grain size (0.544 mm) and filtration velocity (0.136 cm per sec) the coefficient λ_i is higher for Chlorella than Scenedesmus, that is,

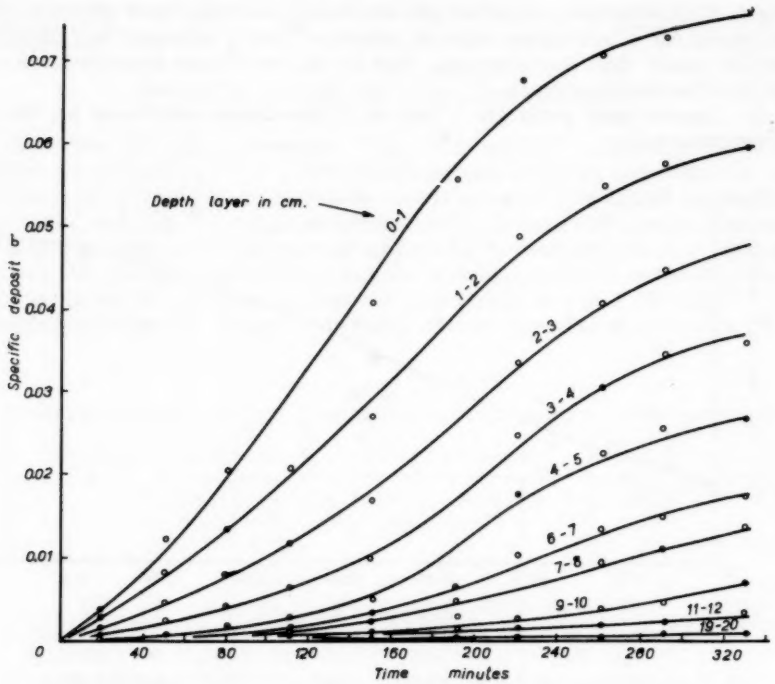

FIG. 3.—INCREASING SPECIFIC DEPOSIT (σ) WITH TIME FOR VARIOUS DEPTH LAYERS (RUN 1B)

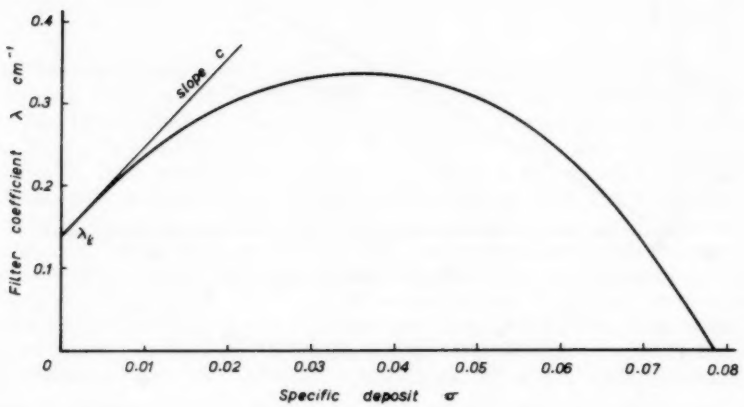

FIG. 4.—FILTER COEFFICIENT VERSUS SPECIFIC DEPOSIT (RUN 1B)

more Chlorella are removed per cm depth of filter than Scenedesmus. Measurement of settlement rates in quiescent water indicated that Chlorella settled faster than Scenedesmus, that is, the results are in accordance with the gravitational hypothesis.

2. Larger sand grain sizes lead to a diminished coefficient λ_i, that is, worse removal.

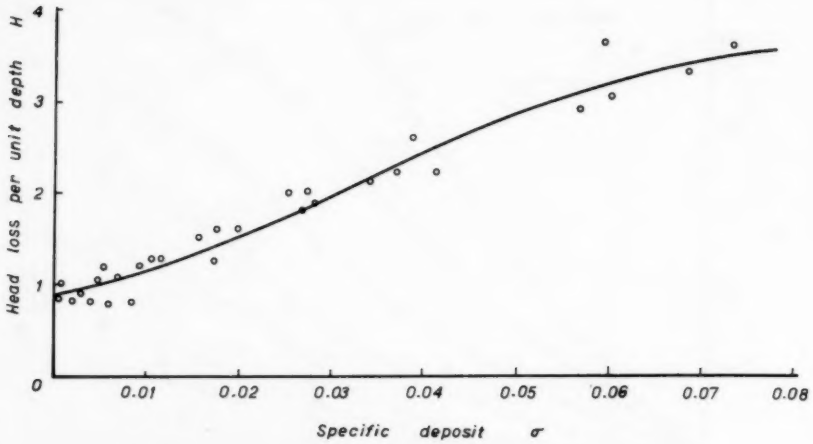

FIG. 5.—HEAD LOSS PER UNIT DEPTH VERSUS SPECIFIC DEPOSIT (RUN 1B)

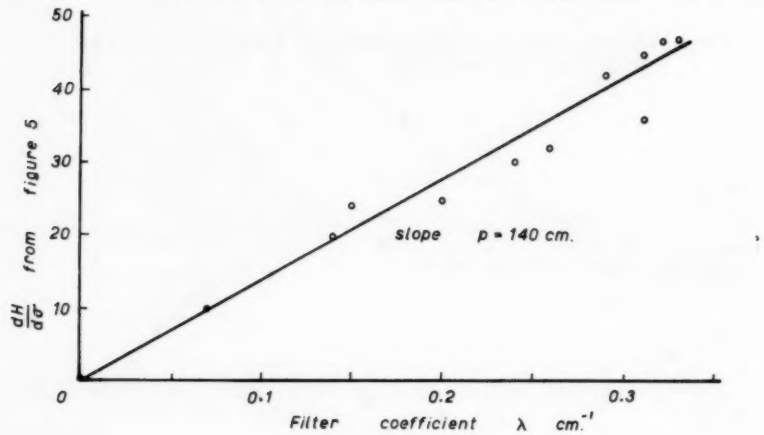

FIG. 6.—EMPIRICAL GRAPH OF $\frac{dH}{d\sigma} = p\lambda$

3. Increasing velocity for a given grain size and suspension causes a diminishing coefficient λ_i, that is, worse removal.

4. The parameter c, although defined theoretically in terms of pore geometry, is dependent on filtration velocity.

The dependence of filtration on initial porosity and temperature was not assessed.

COMPUTED DESIGN AND ANALYSIS CHARTS

With values for the parameters v (filtration velocity), f (initial porosity), λ_i (filter coefficient), c and ϕ (filter coefficient parameters) and p (head loss coefficient) it is possible to simulate numerically filtration on an automatic digital computer for any inflow concentration C_i through any ranges of depth L and time t. As the concentration of suspension is dependent on depth in the filter and on time during the filter run, its correct graphical representation should be three-dimensional co-ordinates as shown in Fig. 7. Similarly the accumulation of specific deposit σ is depth-time dependent as shown in Fig. 8.

TABLE 1

Run No.	Suspension	Sand geo. mean size, in mm	Approach velocity, in cm per sec	Filter parameters				Sand initial porosity	Temperature, in °C
				λ_i, in cm^{-1}	c, in cm^{-1}	ϕ, in cm^{-1}	p, in cm		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1A	Chlorella	0.705	0.136	0.042	3.5	23.5	3100	0.37	25.5
1B	Chlorella	0.544	0.136	0.140	12.0	64.0	140	0.39	23.0
2A	Scenedesmus	0.705	0.136	0.100	7.4	42.0	. . .	0.37	23.0
2B	Scenedesmus	0.544	0.136	0.103	12.1	217.0	1200	0.39	22.5
2C	Scenedesmus	0.544	0.272	0.085	5.6	65.0	340	0.39	26.0
2D	Scenedesmus	0.544	0.408	0.004	1.5	87.0	. . .[b]	0.39	23.5
2E	Scenedesmus	0.250	0.136	0.151	4.0	420.0	2300	0.41	25.0

[a] v = 0.136 cm per sec = 120 gal per sq ft per hr.
[b] Non-linear : $dH/d\sigma = (p\lambda)^3$ (υ = 1950 cm).

It is however more useful to plot these in a two-dimensional form, as has been done in Figs. 9 and 10 from data computed for the conditions specified in run No. 1B in Table 1, that is, Chlorella suspension filtered at 120 gal per sq ft per hr at 23°C through sand of geometric mean size 0.544 mm and porosity 0.39. The initial concentration was 135 ppm (volume per volume). It is of interest to compare Fig. 10 (machine computed) with Fig. 3 (empirical results) to indicate the validity of the computer simulative program. Computed head loss curves are given in Fig. 12, that can be compared with the experimental curves for the same conditions in Fig. 11. From such graphs as Figs. 9 and 12, or better from the computer output tables, it is possible to select rational designs for filter depth, by specifying a certain filtrate concentration that must not be exceeded. Also time between washes can be specified from considerations of the total allowable head loss, or deterioration of filtrate.

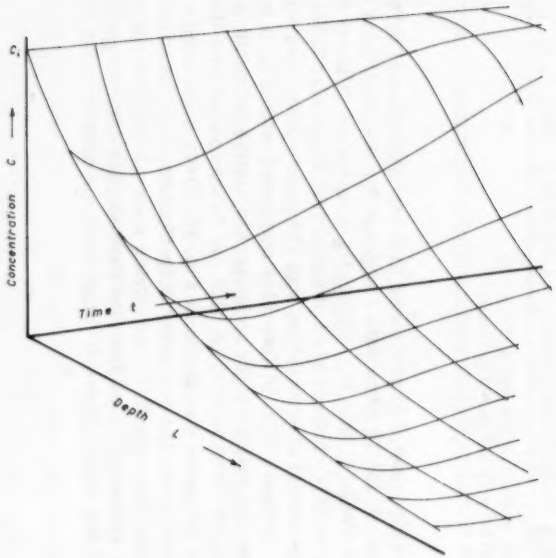

FIG. 7.—THREE DIMENSIONAL RELATIONSHIP BETWEEN CONCENTRATION, DEPTH, AND TIME

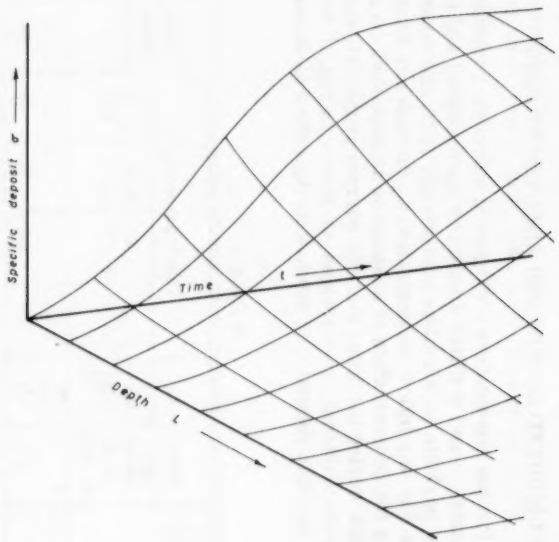

FIG. 8.—THREE DIMENSIONAL RELATIONSHIP BETWEEN SPECIFIC DEPOSIT, DEPTH, AND TIME

If the concentration in the inflow is variable with time, providing this variability is known, its effect on filter behavior can be computed by a modification of the computer program.

FUTURE DEVELOPMENT

Three principal variables of interest to the engineer have not yet been theoretically elucidated. These are the characteristics of the suspension, the size of the filter grains, and the rate of filtration. Minor variables are the porosity of the filter and water viscosity (that is, temperature). It is thought that the settlement characteristic of the suspension as expressed by its Stokes'

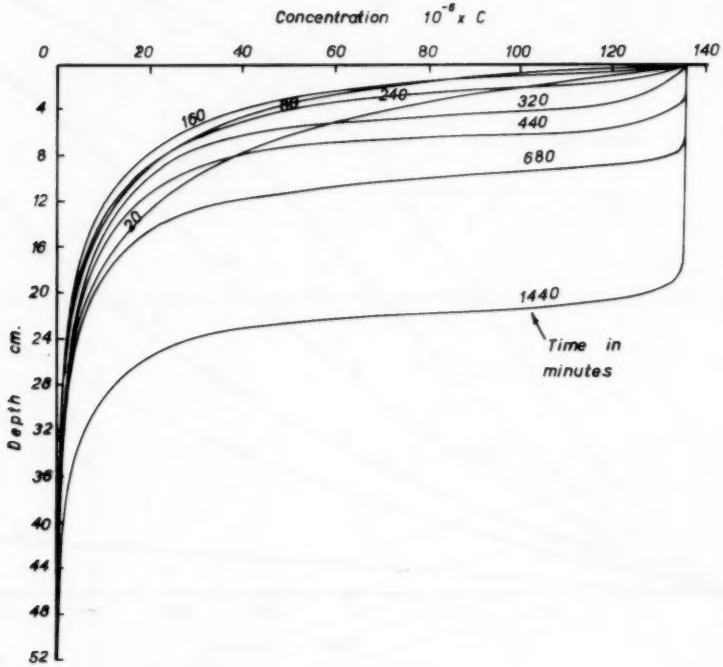

FIG. 9.—COMPUTED CONCENTRATION DISTRIBUTIONS : THEORETICAL (RUN 1B)

settling velocity will be the operative parameter. This is being investigated at University College, London (1961). It is believed that Reynolds number for the state of flow through the filter

$$R = \frac{\rho D v}{\mu (1-f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

(in which D is the grain diameter and μ/ρ is the Kinematic viscosity) will be the operative parameter for assessment of the effect of viscosity, velocity, grain diameter, and porosity as it contains all these essential elements. This has yet to be investigated.

If the theoretical approach is valid an on-site test can be developed for a particular water supply using trial filter media. A portable filter kit for such a test, enabling design data to be produced, is also being developed (1961), at University College.

The methods outlined herein would allow rational comparison of various filter media, and of the effects of preliminary treatments (storage, coagulation, microstraining) on subsequent filtration (where no biological filtration function is involved).

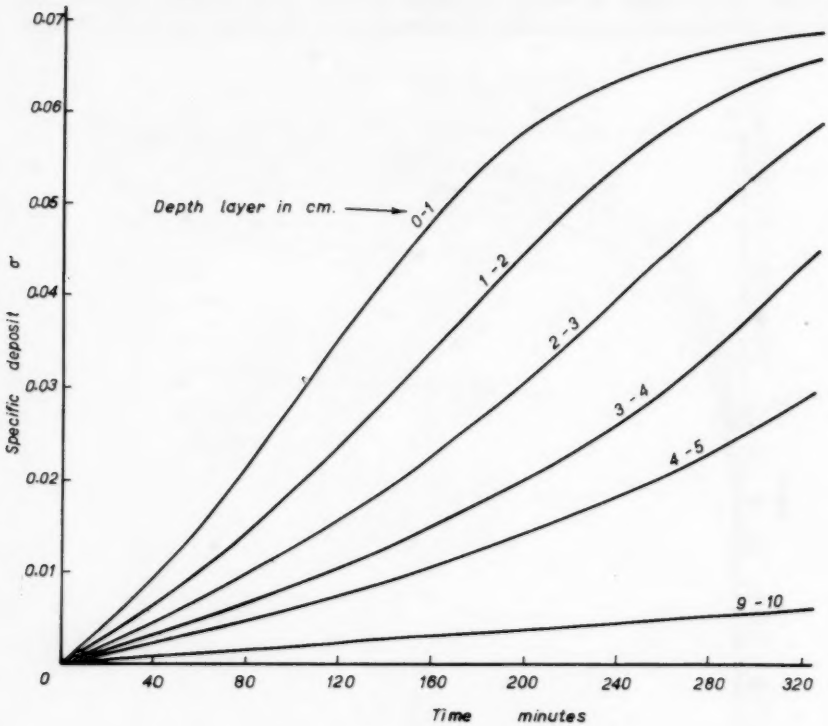

FIG. 10.—COMPUTED SPECIFIC DEPOSIT DISTRIBUTIONS WITH TIME : THEORETICAL (RUN 1B)

The use of radioactive material in this investigation was incidental. It offered a convenient technique, but other non-radioactive methods are available for obtaining the filter parameters.[2]

It is appreciated that the dependence of the computations on an automatic digital computer may be a disadvantage, however, such machines are becoming of increasing application in civil engineering, having great advantages of speed and flexibility. Undoubtedly, simple approximations of the theoretical

equations would be of great value; as yet no satisfactory ones have been produced. Analytical solutions of an extremely simplified filtration equation have been produced by N. V. Ornatskij, et al.,[8] but the theoretical basis of their approach is open to criticism.

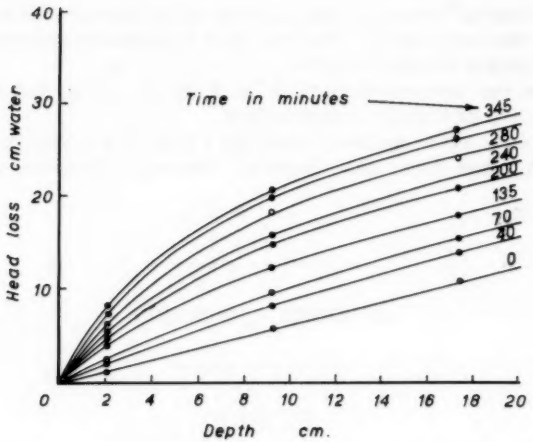

FIG. 11.—HEAD LOSS THROUGH FILTER DEPTH : EXPERIMENTAL (RUN 1B)

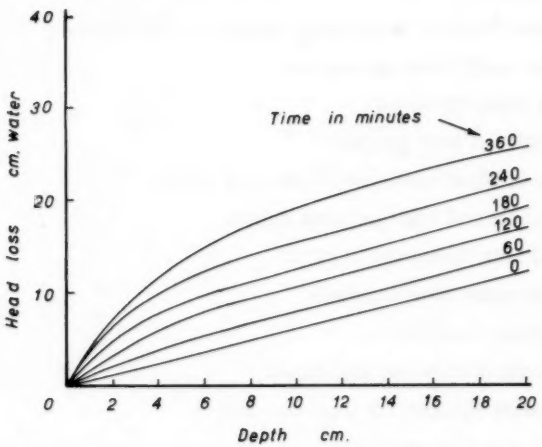

FIG. 12.—HEAD LOSS THROUGH FILTER DEPTH : THEORETICAL (RUN 1B)

In the rapid development of new scientific techniques, there is a challenge to the sanitary engineer, in that he must maintain his place in the advancement of engineering science, and that sanitary engineering research and de-

8 "Investigation of the Process of the Clogging of Sand," by N. V. Ornatskij, E. M. Sergeyev, and J. M. Sechtman, Univ. of Moscow, U.S.S.R., 1955.

velopment should not lag behind because of the research efforts in sanitary chemistry and microbiology.

ACKNOWLEDGMENTS

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The advice and co-operation of G. M. Fair, F. ASCE, and H. A. Thomas, Jr., F. ASCE, are gratefully acknowledged.

Computed data were obtained from the I.B.M. 704 Computer at the Mass. Inst. of Tech., and from the Ferranti Mercury Computer in the Univ. of London.

APPENDIX.—NOTATION

Symbol	Definition	Dimensions
A	= Area of filter perpendicular to flow direction.	L^2
C	= Concentration of suspension in the flow (volume/volume).	
C_i	= Concentration of suspension applied to the filter.	
c	= Filter coefficient parameter.	L^{-1}
D	= Sand grain diameter.	L
f	= Porosity of sand grains.	
H	= Loss of head (water gage) per unit depth.	
H_i	= Initial loss of head per unit depth.	
H_L	= Total loss of head to depth L.	L
L	= Depth below filter surface.	L
p	= Head loss coefficient.	L
Q	= Quantity of flow per unit time.	L^3T^{-1}
R	= Reynolds number for a porous bed.	
t	= Time of filter operation.	T
v	= Approach velocity.	LT^{-1}
λ	= Filter coefficient.	L^{-1}
λ_i	= Initial filter coefficient.	L^{-1}
μ	= Dynamic viscosity of water.	$ML^{-1}T^{-1}$

ρ = Density of water. ML^{-3}

σ = Specific deposit (volume of deposit per unit filter volume).

ϕ = Filter coefficient parameter. L^{-1}

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Proceedings of the American Society of Civil Engineers

DISSOLVED SOLIDS REMOVAL FROM WASTE WATER BY ALGAE

By Albert F. Bush,[1] M. ASCE, John D. Isherwood,[2] M. ASCE, and Shiva Rodgi[3]

SYNOPSIS

The aim of the investigation reported in this paper was to reclaim waste water for eventual re-use. The objective was not only to remove solids but to reduce the dissolved salts concentration which normally increases by 100 to 300 parts per million (ppm) in the domestic use of water, by permitting residential sewage after secondary treatment by the activated sludge process to flow through a third stage algae pond. The study was so designed that the system operated under natural conditions.

The pond, constructed as a third stage to follow the secondary clarifier, was operated at four flow rates. The clarifier effluent was the most suitable in terms of low suspended solids, low BOD, and high algae growth rates, for input to the algae pond. Comparison of the influent and effluent water quality by physical and chemical analysis was made at each flow rate.

Scenedesmus was found to be the predominant algal species, with much smaller concentrations of Chlorella, Euglena, and Diatoms. Scenedesmus grew on the sides and the bottom of the pond, and appeared to be suitable for a continuous flow system. Chemical analysis indicated that considerable quantities of bicarbonates, the nitrogen series, ammonia, nitrates, and organic nitrogen, and phosphates were removed by the algae. Magnesium and calcium were also removed, with less clear indication of the removal of potassium and sulphates. Sodium and chloride showed no appreciable reduction.

The pond effluent water was clear, odorless, and meets United States Public Health (USPHS) standards for potable waters, with the single exception

Note.—Discussion open until October 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. SA 3, May, 1961.

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of bacterial count. The dissolved oxygen content of the pond effluent was high and the dissolved solids concentration was reduced to approximately local tap water levels.

INTRODUCTION

There are many areas both in the United States and throughout the world where the available water supply (as of 1961) may soon become inadequate to meet ever-increasing demands. This is particularly true in arid regions which depend on importation of water to meet current needs. The ever-increasing demands of domestic, industrial, and agricultural users will lead to growing difficulties in expanding the water importation facilities, and to a search for water sources at greater and greater distances from the areas of consumption. The problem is not limited to arid climates. Many areas which have sufficient yearly rainfall to meet present day demands would benefit greatly by the provision of additional water to meet, for example, supplemental irrigation demands during drought periods. The rapid growth of world population makes it essential to plan for water for supplemental irrigation in all areas where increased agricultural production will result.

With existing techniques and knowledge of water treatment processes, waste water can be reclaimed to provide a supplement to the natural water supply system, in addition to which the reclaimed waste water would be available at the point of consumption, and not in some distant watershed. However, at the present time (1961), direct return of reclaimed waste water into a municipal water supply reservoir might meet with considerable resistance on the part of public health authorities. Alternatively, it is possible to provide spreading grounds for the eventual deep percolation of reclaimed waste water to the underlying aquifers. With proper location, spreading grounds could be designed for recreational use and as storage for fire protection, particularly in wild life areas close to population centers. The use of reclaimed water to serve such a multi-purpose function might appeal both to the public and to local and state planning authorities.

One example of direct use of reclaimed waste water is the irrigation of Golden Gate Park in San Francisco, Calif. This is a very acceptable use of waste water and has not met with public resistance. Aquifer recharge, a less direct use of reclaimed waste water, could be achieved through the provision of small lakes for recreational activities such as boating or swimming. In many communities in southern California, for example, such lakes would also be attractive from the point of view of fire protection.

The domestic use of water usually results in an increase of from 100 to 300 parts of dissolved solids per million parts of water by weight (ppm). The use of waste water with no attempt to remove dissolved solids would rapidly lead to a lake water high in salts due to the natural evaporation. A prerequisite to such use of waste water, then, is the removal of some of the dissolved solids. This may be accomplished as a third-stage following a secondary sewage treatment process. The investigations reported in this paper deal with the possibility of utilizing algae in such a third-stage process to remove the dissolved solids from waste water.

William J. Oswald, M. ASCE, Harold B. Gotaas, F. ASCE, have reported[4] stabilization of raw sewage in oxidation ponds by the symbiotic activity of algae (chiefly Chlorella) and bacteria. The main objective of such systems is to minimize the cost of sewage treatment. The present study separates bacterial decomposition, which occurs in an activated sludge plant, from algae growth which takes place in a third stage pond. During growth algae assimilate some of the dissolved solids present in the waste water which is taken from the secondary clarifier of a small activated sludge treatment plant. Raw sewage entering the headworks is from a residential trunk line sewer in West Los Angeles, Calif. This waste water, with a dissolved solids content of about 600 ppm, appears to contain the nutrients necessary for algae growth, and appears not to inhibit growth of certain algae.

The water from the secondary clarifier with a biochemical oxygen demand (BOD) of 7 ppm to 10 ppm, flows through a shallow open trough through which a recirculation pump maintains a mean flow velocity of 0.5 fps. Algae growing naturally in this pond are predominately Scenedesmus with much lower concentrations of Chlorella, Euglena, and Diatoms. These algae were able to flourish in full sunlight, and with a maximum daily variation in pond water temperatures of 65°F to 95°F. Some specific effects of algal growth on the quality of the waste water have been evaluated. The liberation of oxygen by algae satisfies the small BOD remaining after activated sludge treatment, and leads to a pond effluent that is high in dissolved oxygen (DO). Inorganic salts are removed from the waste water by algal growth. Undesirable nitrogenous compound are removed presumably by deamination and utilized by algae to synthesize cell protein. The bacterial population of the water was reduced after passing through the algae pond.

ALGAE PHYSIOLOGY AND WATER RECLAMATION

Photosynthesis is the process whereby plants which possess photosensitive pigments are able to synthesize organic matter and liberate oxygen, in the presence of sunlight, by the utilization of carbon dioxide and water. Pigments such as chlorophyll (green), carotenoids (yellow), and phycobilins (red and blue) are reported in different algae. In the algae species present in the experimental pond, chlorophyll is the principal photosynthetic pigment. Magnesium is a basic element in the structure of the chlorophyll molecule, and the synthesis of chlorophyll by the growing algae thus provides a mechanism for the utilization of magnesium present in the waste water.

The major elements in protoplasm are hydrogen, oxygen, carbon, and nitrogen. Hydrogen and oxygen clearly constitute the water medium itself. It is of interest to survey briefly the available information on carbon and nitrogen assimilation by algae. The need for carbon dioxide in algal photosynthesis is well known and in addition many species are able to utilize bicarbonate as a source of carbon. The direct assimilation of bicarbonate is possible in Scenedesmus according to S. Osterlind.[5] Carbohydrates are formed in the

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[4] "Photosynthesis in Sewage Treatment," by W. J. Oswald and H. B. Gotaas, Transactions, ASCE, Vol. 122, 1957, pp. 73-106.

[5] "Inorganic Carbon Sources of Green Algae I," by S. Osterlind, Physiological Plantology, Vol. 3, 1950, pp. 353-360.

algal cell by the transfer of hydrogen from water to carbon dioxide in the presence of enzymes.[6]

Protein synthesis requires nitrogen in addition to oxygen, hydrogen, and carbon. In the waste water, nitrogen is available from bacterial decomposition of organic material in the activated sludge process. Scenedesmus converts organic nitrogen to ammonia, which is then utilized by the algae in the synthesis of cell material. Nitrate can also be assimilated by this algal species, whereas Chlorella appears to prefer ammonia.[7] There is a considerable diminution in metabolic activity at night when radiant energy is not available from the sun, but this activity does not stop completely. Investigators who have studied this "dark reaction" report the assimilation of carbon, and the utilization of ammonia in Chlorella continues in darkness.

The predominant species of algae in the pond, Scenedesmus, characteristically grew on the sides and bottom of the pond. Scenedesmus is principally a fresh water algal growing in colonies of four or occasionally eight cells in a row. Each cell of the colony divides transversally into two daughter protoplasts which then divide longitudinally, forming four new colonies for each original colony. Chlorella prefers a medium containing greater quantities of organic matter. Chlorella was present in the pond, but in concentrations only about one fifth as high as Scenedesmus. Euglena and Diatoms were also identified in the pond water. They formed less than 5% of the total algae cells.

The pond environment favored the growth of Scenedesmus which in a preliminary three day trial showed a 58% increase in concentration, which would lead to a 100% increase in about 4 1/2 days. A plot of expected cell count based on an initial value of 6,000 per milliliter and a typical colony size of 4 cells is shown in Fig. 1 and indicates that just over seven generations would lead to the final estimated cell count of 180 million cells per milliliter. (The final cell count was estimated taking into account the algae discharged from the pond with the effluent.) The experimental run, from initial seeding to final harvest, lasted 30 days and, in consequence, Fig. 1 gives good support to the preliminary figure of 4 1/2 days generation time since 7 x 4 1/2 = 31 1/2 days.

It will be clear from examination of Fig. 1 that it is very desirable to operate an algae pond in the shaded region to provide effective third stage treatment and appreciable removal of salts. For example, with a concentration of 10 million cells per milliliter the next generation will yield 40 million cells per milliliter and it is the very rapid growth of the newly formed colonies which is of most value in the rapid uptake of salts from the water.

Plant life generally requires adequate nitrogen, phosphorus, and potassium for normal growth. Calcium is also an essential constituent of plant cells. Elements which are required by all algae in very small quantities include iron, zinc, manganese, and copper. Molybdenum and vanadium have been reported as micro-nutrients for Scenedesmus, and silicon for diatoms. It is abundantly clear from the foregoing that the synthesis of cell material by the

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6 "Photosynthesis," by E. I. Rabinowitch, Scientific American, Vol. 178, No. 8, 1948, pp. 25-35.

7 "Studies on Chlorella Vulgaris, III," by R. Pratt and J. Fong, American Journal of Botany, Vol. 27, 1940, pp. 735-743.

growing algae provides a mechanism for the removal of many dissolved solids from waste water.

ENVIRONMENTAL CONDITIONS

The photosynthetic process leads to the release of free oxygen, which has been shown[8] by S. Ruben, et al., to come from water, rather than from carbon dioxide. Super-saturation of the medium with oxygen results in some inhibition of photosynthesis but the inhibition is reduced if the carbon dioxide supply is high.

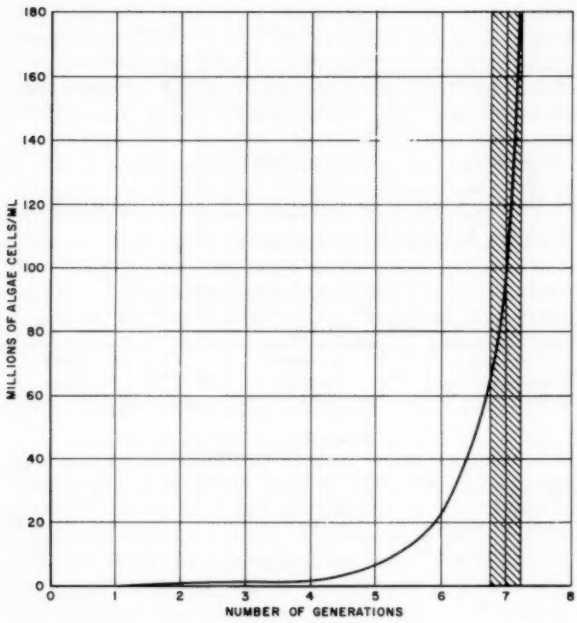

FIG. 1.—EXPONENTIAL GROWTH CURVE FOR SCENEDESMUS SP.

Algae can survive a wide variation in temperature, but maximum growth rates for Chlorella occur between 68°F and 86°F according to J. Myers.[9] Water temperatures below 41°F or above 95°F are reported as inhibiting growth, although a thermophilic strain of Chlorella which grew well at 102°F has been mentioned in the literature.

Most algae flourish at a pH between 7.0 and 8.5 with higher or lower values leading to growth inhibition. A frequent observation is the rapid rise in the

8 "Heavy Oxygen (18) as a Tracer in the Study of Photosynthesis," by S. Ruben, M. Randall, M. Kamen, and J. L. Hyde, Journal, Amer. Chem. Soc., Vol. 63, 1941, pp. 877–879.

9 "Growth Characteristics of Algae in Relation to the Problems of Mass Culture," by J. Myers, Carnegie Inst. Wash. Pub., Vol. 600, Chap. 4, 1953, pp. 38–54.

pH of the medium, up to as high as pH 11, during active photosynthesis. This has been attributed to the removal of nitrates and carbon dioxide from the medium. The pH may be held to the desirable limits by the addition of an adequate supply of carbon dioxide.

PHYSICAL FACILITIES AND PLANT OPERATIONS

A U-shaped algae pond 55 ft long, with a trapezoidal cross section was constructed for use as a third stage in an activated sludge plant. At 4 1/4 in. depth the pond holds 145 gal of water. The pond water is kept in continuous circulation, which tends to maintain the homogeneity of temperature, hydrogen

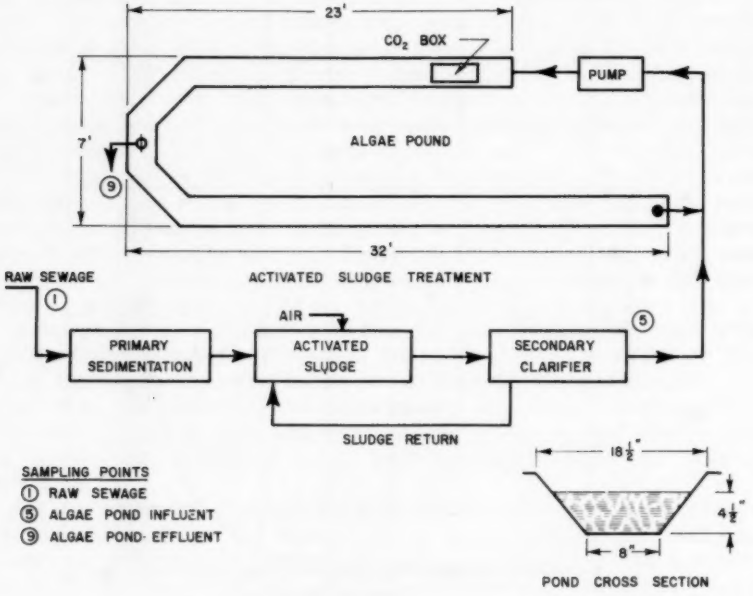

FIG. 2.—WATER RECLAMATION PLANT FLOW SHEET

ion concentration, and nutrients in the medium. Waste water from the secondary clarifier of the activated sludge plant flowed continuously through the pond supplying nutrients and removing metabolic wastes. The selection of the effluent from the secondary clarifier (sampling point 5, Fig. 2) as a medium for algal growth was based on preliminary trials with water samples from various stages in the activated sludge treatment plant. Algal growth downstream from sample point 5, that is, in water taken from the sand filter and the chlorinated clear water tank, was much less than in sample point 5 water. Upstream from this point higher BOD, suspended solids, and bacterial count led to the choice of the secondary clarifier effluent as the most suitable for third stage algal treatment.

Exhaust gas from a natural gas burner supplied carbon dioxide continuously to maintain the hydrogen ion concentration in the medium between 7.0 and 8.5. A mixture of natural gas and air (1:5) was burnt which produced an exhaust gas containing 8% carbon dioxide. The burner was covered by a box, in which a slight excess pressure was maintained to facilitate gas absorption in the water. Absorption is mainly a surface contact process and carbon dioxide is taken into the water in relation to the differential concentration gradient. With this one exception (that is, the supply of carbon dioxide to maintain pH close to optimum) the pond was operated with no control of temperature, light intensity, influent quality and so on, in order that the data would be representative of the type of results obtainable in practice. Under natural conditions, artificial constraints imposed on the environmental variables are not feasible in current (1961) sewage treatment practice, and were deliberately avoided.

Fig. 2 represents the flow sheet. The sewage treatment plant consists of a settling unit, activated sludge unit, secondary clarifier, filtering unit, and clear water tank. The arrows indicate the sewage flow through the treatment process. The activated sludge treated water leaving the secondary clarifier by-passed the filtering unit and the clear water tank, and entered the algae pond. This water was allowed to flow into the pond continuously for a period of 30 days. Comparisons of the quality of the influent with that of the effluent were made at four different flow rates (5, 10, 20.7, and 58 gal per hr). The detention periods at these flow rates were 29.0, 14.5, 7, and 2.5 hr, respectively. The lower flow rates were used in the early part of the investigation; the higher rates used when the algae population had increased considerably. At the conclusion of the experimental run, the pond was drained and algae (growing mostly on the sides and bottom of the pond) were harvested.

SAMPLING METHODS AND ANALYTICAL PROCEDURES

Three sampling methods were employed. Grab samples were collected at 9 a.m., 12 noon, and 3 p.m. from both influent and effluent simultaneously. At the higher flow rates, 20.7 and 58 gal per hr, the detention time in the pond was 7 hr and 2 1/2 hr respectively. At these flow rates follow-up samples were taken. The influent was sampled and after the lapse of the detention time the effluent was then sampled in an attempt to follow the same parcel of water through the system and measure its change. A trickling method was employed to sample, continuously, both influent and effluent over a 24-hr period and samples thus taken were designated composite.

Total dissolved solids, electrical conductivity (EC), and hydrogen ion concentration (pH) were determined for all samples. For most chemical analyses "Standard Methods" (1955) was followed although certain methods were slightly modified. The concentration of calcium, magnesium, potassium, sodium, bicarbonate, phosphate, sulfate, chloride, ammonia, nitrate, and organic nitrogen was determined. Biological analyses include both algae and bacteria counts. The number of algal cells per milliliter was determined for each sample since some algae were carried out of the pond with the effluent. Bacteria count was measured by determination of the most probable number (M.P.N.).

The relationship between cell count, packed volume, and dry weight of the algae was determined prior to the salt removal studies. The algae pond was filled with activated sludge-treated water and only sufficient influent was ad-

mitted periodically to compensate for evaporation losses. A sample of about a liter was collected daily, after the algae pond was thoroughly stirred. After shaking the sample bottle, 5 ml of the liquid was taken and diluted to 50 ml with distilled water. The dilution was found necessary to facilitate counting of cells, as the samples were highly concentrated. The cell count of each of the algal species was made with a hemocytometer cell under 430x magnification. The cell number thus obtained was multiplied by the dilution factor to determine the number of cells per milliliter of the sample.

From the original sample, a one liter portion was centrifuged at 2,500 rpm for 6 min in four 250 ml bottles. The clear supernatant liquid was decanted and the algal cells were transferred to 15 ml graduated centrifuge tubes, care being taken that all the cells were transferred to the tubes. The 15 ml tubes were spun at 3,000 rpm for 3 min to determine the packed volume of algae. After draining, these tubes were placed in an oven overnight (14 hr to 16 hr) at 103°C. The tubes were allowed to cool in a dessicator, and the dry weight of algal cells was determined on an analytical balance.

RESULTS OF ALGAE POND STUDY

Fluctuations in algae pond hydrogen ion concentration between pH 7.0 to pH 11 were observed as shown in Fig. 3 in which typical results of measurements of pH are shown when CO_2 is added for control. The demand for carbon dioxide by the rapidly growing algal population was high, and an absorption area of 3.7 sq ft was necessary to maintain hydrogen ion concentration in the optimum range (pH 7.5 to pH 8.5).

Bicarbonate concentration in the influent waste water was high (generally 200-320 ppm) but at the low input rates (5 or 10 gal per hr), total bicarbonate input including that derived from carbon dioxide was apparently insufficient to satisfy the algal demand for this ion. The pond pH consequently increased during this part of the investigation to as high as 10.9, at times of peak daytime algal activity. At 20 or 58 gal per hr the total quantity of bicarbonate ions entering the pond per unit time in the waste water was sufficient to enable the carbon dioxide supply to control pH more effectively, and fluctuations were limited to between pH 7.5 to pH 8.5.

Fig. 4 gives results of hourly measurements for a 28-hr period. The influent pH remained practically constant at 7.6 to 7.9; the effluent pH increased rapidly from 8:00 a.m. until 12:00 noon, and remained almost constant until 6:00 p.m. With the reduction of light and solar radiation, the algal activity decreased and the demand for carbon dioxide was reduced sufficiently to reverse the day time pH pattern. Effluent pH at night fell below that of the pond influent, and this pattern persisted until algal activity commenced the next morning. The relationship of pH to other environmental variables is shown in Fig. 5.

Solar radiation was measured with a flat plate radiometer (Gier and Dunkle type). The radiation intensity increased rapidly from about 6:00 a.m. until 9:00 a.m. It continued to increase gradually, reaching a peak of 460 BTU per sq ft hr between 12:00 noon and 1:00 p.m. This maximum intensity was remarkably consistent over the period of the investigation. From 1:00 p.m. until 8:00 p.m. a gradual reduction in intensity was observed, as shown in Fig. 5. Light intensity followed the solar radiation pattern with a slightly longer peak period usually from 12:00 noon until 2:00 p.m.

The pond water temperature variations showed a cyclic pattern similar to solar radiation. The maximum occurred close to 2:00 p.m., but the temperature was frequently almost constant between 12:00 noon and 4:00 p.m. Maximum and minimum water temperature during the investigation were 95°F and 55°F, respectively. The daily temperature changed by 28°F to 37°F.

Throughout the period of investigation the dissolved oxygen (DO) was above the expected saturation point for the temperature at all times. The DO

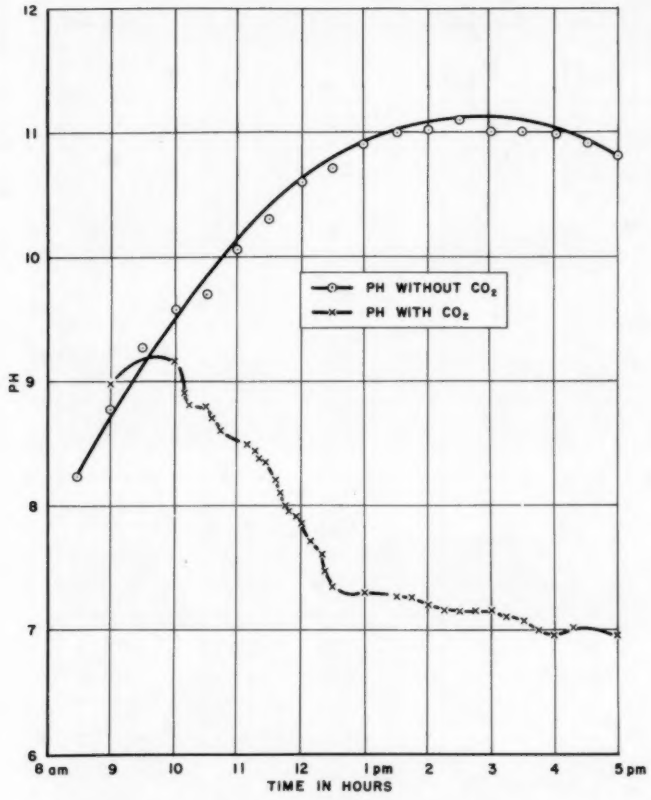

FIG. 3.—EFFECT OF CARBON DIOXIDE ON pH IN ALGAE POND

values were usually slightly higher in the morning than in the afternoon. Increased algal activity during the mid-day led to a greater rate of oxygen production. Gas bubbles were observed being released to the atmosphere, and consequently DO could not be used directly as a measure of algae growth or activity. The DO in the effluent ranged from 9 ppm to 12 ppm and was about double that of the influent (3-7 ppm). In the 28-hr study of algae pond conditions shown in Fig. 5, DO in the effluent remained between 13-17 ppm during

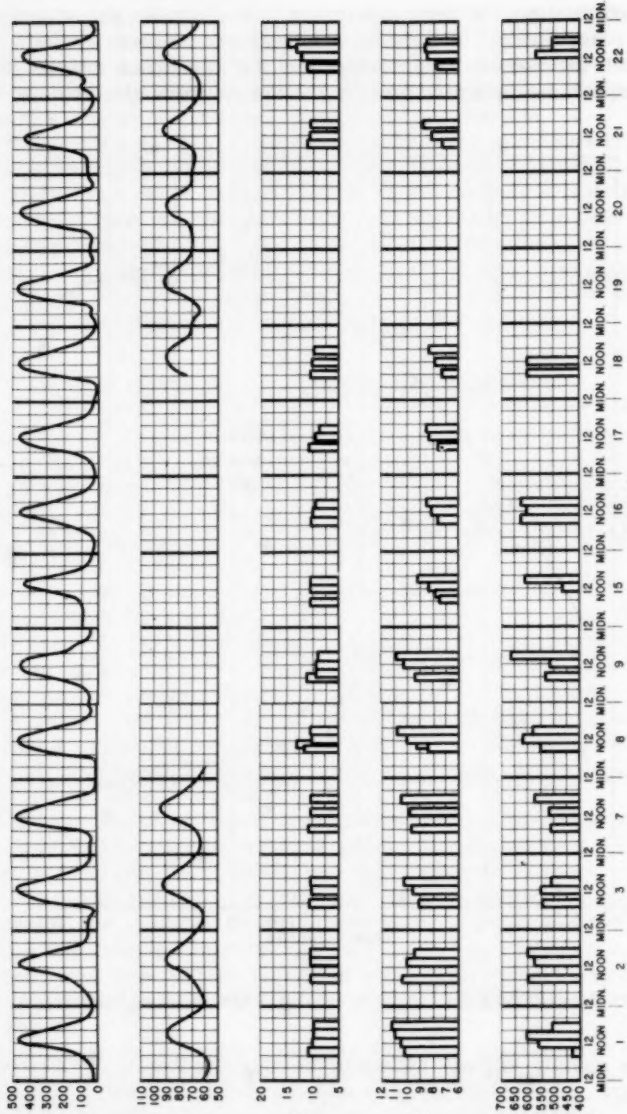
SOLAR RADIATION BTU-HR/FT²
POND TEMPERATURE °F
DISSOLVED OXYGEN PPM
pH
ELECTRICAL CONDUCTIVITY MICROMHOS / CM
MIDN. NOON MIDN.
1 2 3 7 8 9 15 16 17 18 19 20 21 22
JULY 1958

FIG. 4.—TYPICAL RESULTS OF MEASUREMENT OF SEVERAL ENVIRONMENTAL VARIABLES

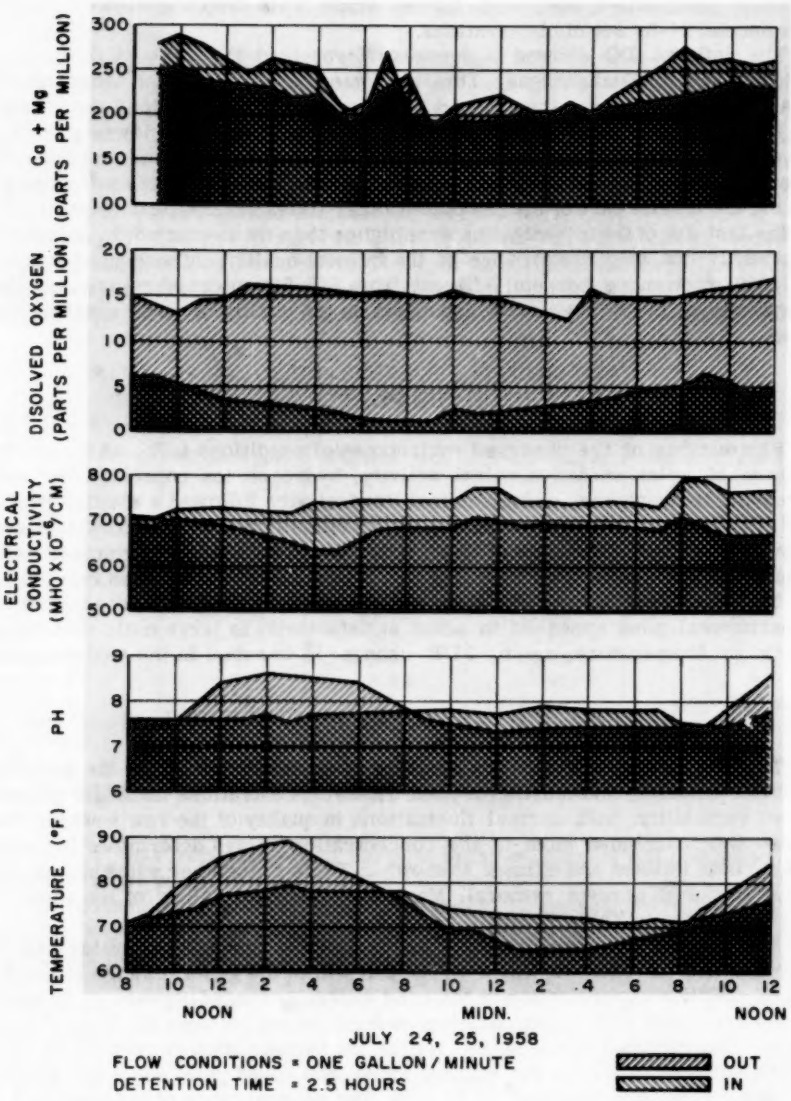

FIG. 5.—POND CONDITIONS FOR 28-HR PERIOD

the entire period. The very small drop in DO (15-12.8 ppm) between 12:00 midnight and 3:00 a.m., and the rapid increase in DO at 4:00 a.m. (12-16 ppm) remains unexplained, and needs further study. This drop was also evidenced in a second 24-hr set of observations.

The influent DO showed a decrease throughout the day until 7:00 p.m., followed by a gradual increase. This trend was presumably due to temperature effects, but the pattern may in part be influenced by organic load variations.

The electrical conductivity (EC) of the effluent was always lower than that of the corresponding influent, 465-665 micromhos per cm and 605-740 micromhos per cm, respectively. The magnitude of the difference was greater during the middle part of the day than at other times (Fig. 4). EC values taken on the last day of the investigation were higher than those commonly observed, apparently due to a disturbance of the influent quality. Influent ranged from 712-800 micromhos per cm; effluent from 645-690 micromhos per cm. The magnitude of the EC is clearly dependent on the quality of water entering the pond.

CYCLIC NATURE OF THE PHYSICAL ENVIRONMENT

Fluctuations of the observed environmental conditions followed the cyclic pattern of solar radiation. Algal activity, hydrogen ion concentration, salt removal, temperature, and electrical conductivity followed a similar cyclic pattern which did not seem to have harmful effects on the algal growth. Algae growing naturally in bodies of fresh water would not, except perhaps in very small shallow ponds, find the daily environmental fluctuations as marked as in the experimental system. It is noteworthy that the algae growing in the experimental pond appeared to adapt satisfactorily to large daily variations (such as temperature, up to 37°F change in one day) in the environment.

INFLUENT AND EFFLUENT ION CONCENTRATION

The concentration of each ion measured was determined from the samples of water entering, and leaving the pond. These concentrations naturally showed some variability, with normal fluctuations in quality of the raw sewage. The range which included most of the concentration values determined for each ion, in both influent and effluent, is shown in Table 1, together with the comparable range of percent removal. Maximum recorded values of ion removal are also listed in Table 1.

The various ion concentrations in the influent and effluent water will be summarized, and values which do not fall within the general range are indicated. Calcium concentration in the pond generally ranged between 42.66 ppm. In the early part of the study, calcium concentrations between 32-36 ppm were found. The samples taken at the end of the investigation showed 69-74 ppm in the influent, whereas the effluent range was 20-53 ppm, and a few (three) readings were found between 60-70 ppm. The general range of magnesium ion concentration in the influent was 12-18 ppm, and in the effluent it was 8-15 ppm. Potassium levels in the influent (6-16 ppm) were apparently adequate. The uptake of this ion by the algae was surprisingly small and only 1/3 of the runs showed a definite reduction in potassium. The influent and effluent concentrations for both chloride and sodium ions were almost identical (52-68

ppm for sodium, 42-60 ppm for chloride) and, moreover, usually showed a slight increase in the effluent concentration. However, these higher values appeared to fall within the limits of the increase in concentration due to evaporation losses.

The influent concentration of the bicarbonate ion was far greater than that of any of the others and ranged between 200 ppm to 320 ppm with one usually high reading of 430 ppm. The effluent concentrations generally ranged between 80-180 ppm. The samples collected during the night hours indicated no removal of bicarbonate at night. Together with the night time depression of pH this provides good evidence of the formation of bicarbonate from carbon dioxide, which was supplied continuously 24 hr a day.

Second only to the bicarbonate ion in terms of concentration, were the sulfates which varied between 70-110 ppm in the pond influent. The effluent values generally ranged between 72-102 ppm, and showed relatively little demand for this ion by the algae. Some variation in sulfate concentration of

TABLE 1.—RANGE OF INFLUENT AND EFFLUENT CONCENTRATION AND PERCENTAGE REMOVAL OF IONS

(1)	Influent ppm (2)	Effluent ppm (3)	Percentage Removal (4)	Maximum Percentage Removal (5)
Calcium	42-66	20-53	2-30	38
Magnesium	12-18	8-15	7-44	44
Sodium	52-68	50-72		
Chlorine	42-60	42-67		
Bicarbonate	200-320	80-180	50-80	90
Sulfate	76-110	76-102	7-40	41
Phosphate	5-15	2-9	19-68	76
Ammonia	4-7	0-2.5	63-90	
Nitrate	2-14	1-4	27-60	93-100
Organic Nitrogen	1-5	0-1.5	32-74	
Potassium	6-16	6-11	6-17	38
Total	470-496	315-470	21-39	39

the influent was recorded, up to 150 ppm in three samples and one unusually high one of 248 ppm.

The concentrations of all other ions were, in general, very much lower than the major ones previously described. Usually the phosphate concentration in the influent was 5-15 ppm, and that of the effluent 2-9 ppm. In the influent, ammonia was found to be 4-7 ppm. However, two samples showed less than 2.5 ppm and three samples were close to 10 ppm. The effluent concentrations of ammonia were generally less than 2.5 ppm with a few samples up to 5 ppm. The general range of nitrate concentration in the effluent was 2-14 ppm, and 1-4 ppm in the effluent. The nitrate concentrations of both influent and effluent follow-up samples were very high (20-60 ppm) which may perhaps be attributed to an unavoidable delay in the analyses of the samples. The organic nitrogen in the influent ranged between 1-5 ppm, and in the effluent 0-15 ppm.

The general ranges of concentration of the various ions indicate the quality of the influent and effluent from the pond. The influent of the pond contained 470-496 ppm total ions, while the reclaimed water had 315-470 ppm total

ions. The average values of total ions in ppm for different detention periods are shown in Table 2.

The EC of the influent in general ranged between 600-740 micromhos per cm at 25°C. The majority of the effluent samples ranged between 460-630 micromhos per cm with a few readings as high as 690 micromhos per cm.

EFFECTIVENESS OF ALGAE IN THE REMOVAL OF SALTS

The effectiveness is determined in terms of the percent removal of ions from the water. The percent removal of calcium, magnesium, bicarbonate, sulfate, phosphate, ammonia, nitrate, and organic nitrogen, was usually higher during the mid-day, that is, between 12 and 4 p.m., than in the morning hours. The salt removal appears to follow the general trend of the algal activity which starts in the morning, increases and reaches the peak between 12 p.m. and 4 p.m., and gradually decreases as the intensity of light drops with the sun. The level of algal activity was reflected in the change in hydrogen ion

TABLE 2.—MEAN PERCENTAGE REMOVAL FOR DIFFERENT FLOW RATES AND SAMPLING METHODS

Kind of Samples (1)	Flow Rate, in gallons per hour (2)	Detention Time, in hours (3)	Influent ppm (4)	Effluent ppm (5)	Difference ppm (6)	Percentage Removal (7)
GRAB	5	29.0	538.2	360	178.2	33.1
	10	14.5	528.6	324.3	204.3	38.7
	20.7	7.0	483.6	342.0	141.6	29.3
	58	2.5	538.4	423.2	115.2	21.4
FOLLOW UP	20.7	7.0	627.0	567.0	60.0	9.6
	58	2.5	636.6	470.6	166.2	26.1
COMPOSITE	20.7	7.0	687.3	534.4	152.9	22.4
	48	2.5	696.7	505.0	191.7	27.5

concentration between 12 p.m. and 4 p.m., and it appeared to be a direct consequence of the corresponding physical environmental conditions.

This direct relationship between the desalinization process, and algal activity and the environmental conditions, was further demonstrated in the follow-up samples. The percent removal of ions at 2.5 hr of detention time during the second (12:30 p.m.-3:00 p.m.) and the third set (4:00 p.m.-5:30 p.m.) of samples was higher than found in the morning set (10:00 a.m.-12:30 p.m.) of samples. In the follow-up samples collected at 7 hr detention time, the percent removal values of the first two sets of samples collected during 8:00 a.m. to 10:00 p.m. indicated a definite reduction in the various ions. A negative removal was observed in the samples collected during night hours 10:00 p.m.-5:00 a.m. Calcium and magnesium removal on an hourly basis are

shown in Fig. 4 and clearly reflect the difference in algal activity during day time and night time.

SPECIFIC ION REMOVAL AND DETENTION TIME

A maximum of 38% removal of calcium at 29 hr detention time when the pH was 10.9, and a minimum of 1.6% removal at 7 hr detention when the pH was 8.7, was recorded. The low values of percentage removal of calcium at all flow rates appeared to indicate a plentiful supply of this ion. The percent removal values for magnesium were usually higher than those of calcium, and followed a similar trend: 44% at 29 hr, falling to 7% at 7 hr detention time with a pH of 8.7. The removal of potassium was highly variable, with several samples showing negative removal. A maximum of 17% removal was recorded for potassium. Preliminary analysis of the algal cell material indicated 0.30% sodium and 0.32% chloride (of dry weight) showing some sodium and chloride removal, although this was not large enough to be detected in the water analyses.

The bicarbonate ion percent removal normally ranged between 50% and 80%. This high percentage removal was observed despite a continuous supply of carbon dioxide. For sulfate, the percentage removal values were from 7% to 40%. The phosphate values ranged between 19% and 68% removed. It would appear that at low flow rates the algal activity was limited by the phosphate availability in the pond. With the high flow rates, algal activity was apparently stimulated by the greater availability of this ion, which resulted in an increased removal of both phosphate and other ions. The percent removal values for ammonia ranged between 63% and 90%, which indicated a high demand for this ion. Nitrate removal values ranged between 27% and 60% while organic nitrogen indicated between 32% and 74% removal.

The mean influent and effluent concentrations for samples at each flow rate presented in Table 2 can be regarded as representative of the overall pond performance at each detention period under the conditions of the run. The total ion removal values were 33%, 39%, 29%, and 21% for 29 hr, 14.5 hr, 7 hr, and 2.5 hr detention respectively. The general range of removal of total ions was from 20% to 40%. A few readings indicated removal as low as 15% to 20% while two with values of 50% to 52% were recorded.

ANALYSIS OF RESULTS

The removal of an ion from the medium depends upon the availability and the relative demand for the ion by the growing algae. The rate of uptake of ions for which there is demand is directly related to the concentration of algal cells and the rate of photosynthetic activity. The specific ions absorbed by the algae in the present investigation were in agreement in all respects with the nutrient absorption studies made by R. W. Krauss,[10] and Krauss and W. H. Thomas[11] using pure Scenedesmus cultures. Most of the ions showed considerable variability in the percentage removal values, ranging from high positive removal to, in some samples, negative values. However, the majority of

10 "Inorganic Nutrition of Algae," by R. W. Krauss, Carnegie Inst. Wash. Pub., Vol. 600, Chap. 8, 1953, pp. 85-102.

11 "The Growth and Inorganic Nutrition of Scenedesmus Obliquus in Mass Culture," by R. W. Krauss and W. H. Thomas, Plant Physiology, Vol. 29, 1954, pp. 205-214.

the samples fell within fairly well defined ranges (Table 1) with only a few extremes outside the ranges shown. The nitrogen series of ions, ammonia, nitrate, and organic nitrogen showed, as would be expected, a high removal, in fact up to complete removal in some cases.

Other ions that showed a considerable reduction in concentration were bicarbonate and phosphate. Maximum removal of bicarbonate was 90%, and that of phosphate 76%. Both of these are well recognized as major plant nutrients, and their utilization by the algae was therefore not unexpected. Potassium, normally considered a major plant nutrient showed considerable variability in the percentage removal and in fact many of the samples indicated a negative removal of potassium. One sample gave a maximum percentage removal of 38% for this ion. The removal of sulphates showed appreciable variability with about half the samples indicating negative removal. The maximum removal for the sulfate ion was 41%. The range of calcium removal was wide, from 1% to 38% with several negative removal readings. The mean percentage removal for this ion was less than 10% although two readings were as high as 38%. Magnesium which is a basic element in the structure of the chlorophyll molecule, was more readily assimilated than calcium and potassium and only an occasional negative removal reading was obtained. The magnesium concentrations (12-18 ppm) in the activated sludge-treated water appeared to be greater than required for the growth of algae. About 55% of the magnesium ions present in the influent were still left in the algae pond effluent. It is possible that the calcium removal at the higher pH levels may have been partly by precipitation as a carbonate and partly by absorption of the ion by the algal cell. Fresh water algae typically require little sodium or chloride, and the lack of removal of either of these ions was therefore not unexpected.

EVAPORATION EFFECTS

Open ponds are, of course, subject to natural evaporation. The data reported are those actually obtained from the experimental pond with no attempt to adjust for the evaporation effect which, with no algal activity, would lead to an increase in dissolved solids concentration in the effluent.

A mean evaporation loss of 0.28 in. of water per day or 12.5 gal for the pond was established under environmental conditions similar to those of the investigation period. At 5 gal per hr input, evaporation alone would have increased the effluent concentration by about 12%. The fact that a decrease in effluent concentration was observed under these conditions means that the actual uptake of dissolved solids was greater than the figures on the influent-effluent concentration difference would indicate. Following the experimental work by W. W. Mansfield,[12] 1 ml of cetyl alcohol kerosene mixture (30 g of cetyl alcohol per liter of kerosene) was spread on the 5.3 sq ft surface of a tank adjacent to the algae pond. A preliminary four day test indicated 30% reduction in evaporation loss. A quantitative study of algal growth rates was

12 "The Influence of Monolayers on the Natural Rate of Evaporation of Water," by W. W. Mansfield, Nature, Vol. 175, 1955, p. 247.

not undertaken, but no visibly detrimental effects were observed on algae growing in the tank.

SOLAR ENERGY

The high incident radiation measured by the flat plate radiometer is a combination of direct and diffuse radiation. To obtain a figure for the direct incident radiation in the visible portion of the spectrum, the estimated total direct radiation falling on the pond was reduced by a factor of 0.45. This is the ratio of visible to total radiation. With these assumptions the total incident radiation in the visible region for the period of investigation was 35,000 BTU per sq ft or 2,410,000 BTU for the 69.4 sq ft of pond surface. Energy liberated by the dry algae, determined by oxygen bomb calorimeter, was 6,820 BTU per lb or 95,000 BTU for the total algae crop. Utilization of solar energy was therefore $\frac{(95{,}000 \times 100)}{(2{,}410{,}000}$ percent, or 4%, which is more than double the efficiency for most agricultural crops.

Scenedesmus, which in the high concentrations found in the latter part of the experimental period was observed to cling to the sides and bottom of the pond forming a mat-like growth, is a highly suitable organism for a system in which a continuous through-put of water is desired. At intervals the pond can be dewatered and the algae collected. This appears to be somewhat simpler than the removal systems used for Chlorella. It is important to emphasize that the cells must be separated from the water in a live state to accomplish salt removal. Inorganic salts were found to be 25% to 28% of dry weight of the algal cells. There is no doubt from these studies that salt can be removed from the water. It may be appropriate to compare the reclaimed water with drinking water standards.

WATER QUALITY

Attempts to set standards of quality of water acceptable for all water supply systems have not been successful because it is difficult to set rigid standards which will not include unsatisfactory waters or exclude potable waters. However the continued demand to have an acceptable measure for water quality has resulted in the adoption of standards[13] by the United States Public Health Service (USPHS) for the quality of water on interstate carriers. The chemical and physical quality of the reclaimed water is comparable in all respects to these standards. The dissolved solids (325-550 ppm) and the magnesium (8-15 ppm), chloride (45-60 ppm), sulfate (50-100 ppm) concentrations, and other ions in the reclaimed water are less than the corresponding upper limits for fresh water set by the USPHS. In fact, for many ions the concentrations in the reclaimed water are less than in the laboratory tap water, the latter being presumably a fair index of water quality in the surrounding residential area from which the sewage is derived. The reclaimed water is clean and has no objectionable odor. The questions of the significant level of nitrates, detergents, and virus which are not specifically mentioned in the standards still remain unanswered.

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13 "Drinking Water Standards," U. S. Public Health Service, Journal, Amer. Water Works Assn., Vol. 38, 1946, pp. 360-370.

Some authorities have suggested[14] that water containing less than 10 ppm of nitrate nitrogen is considered safe for infants, and in general the range of nitrates in the reclaimed water is well below this value (0-4 ppm). On a few tests, however, the nitrate concentrations were found to be higher than 10 ppm.

The total ion concentration which was 255 ppm in tap water increased to 520 ppm after domestic use, but returned to 265 ppm (that is, almost the initial concentration) after activated sludge and third stage algae pond treatment.

The results indicate a method of removing salts from brackish water. When it is economically feasible to consider the use of reclaimed water in a community for any purpose this method could be considered as a part of a treatment system for removal of salts.

USE OF RECLAIMED WATER

Several alternative uses of reclaimed waste water are possible without effluent chlorination. The water may be discharged into natural or artificial

TABLE 3.—COLIFORM AND ENTEROCOCCUS MPN. PER ML IN ALGAE POND INFLUENT AND EFFLUENT

Date	Time	Influent		Effluent	
		Coli	Entero	Coli	Entero
(1)	(2)	(3)	(4)	(5)	(6)
9/3/58	3 p.m.	400	110	18	18
9/25/58	1 p.m.	300	80	1.1	2.3
10/2/58	10 a.m.	130	130	0.2	2000
10/14/58	1:30 p.m.	24000	5400	24+	24+
10/23/58	10 a.m.	540	70	1600	4.9
10/30/58	10 a.m.	490	70	490	4.5

basins to be used for recreational purposes such as boating or swimming. If suitably located such lakes would be a valuable asset for both community and forest fire protection, particularly in localities where the forest fire hazard is high, as in many foothill areas in Southern California. Aquifer recharge through new or existing spreading grounds is a very satisfactory method for augmenting natural ground water recharge, and chlorination would be unnecessary since bacteria travel through porous media is limited to a few feet.

The reclaimed water quality is satisfactory for irrigation of all crops, with the exception of leaf vegetables, which are eaten uncooked. There are many areas where the availability of supplemental irrigation water has led to large increases in crop yields. To provide an adequate food supply for the rapidly expanding world population will require that supplemental irrigation water be made available in all localities where such water can lead to increased yields. Reclaimed waste water can meet this need. The quality of this water is also suitable for many industrial purposes without chlorination.

14 "Water Quality Criteria," California State Water Pollution Control Bd., Publication No. 3, 1952.

Effluent from the algae pond as operated during this investigation would require chlorination to meet USPHS standards for potable water. The bacterial population however is not high (Table 3) and in fact is appreciably reduced in passing through the pond.[15] Optimization of the pond operation may lead to an effluent that meets drinking water standards without chlorination. Such effluent could be returned directly to water supply reservoirs.

CONCLUSIONS

Sewage from a residential area when treated by the activated sludge process followed by a third stage algae pond can be reclaimed to yield an effluent of high quality. Total dissolved salts were reduced from 520 ppm to 265 ppm, which is approximately local tap water quality. To accomplish removal of dissolved salts a continual and rapid increase in algal population is necessary. This was facilitated by the addition of carbon dioxide to the water. The algae must be harvested in a live state to ensure removal of salts stored in the cells, from the water. The predominant algal species was Scenedesmus which clings to the sides and bottom of the pond. Periodic dewatering and scraping would be a satisfactory procedure for harvesting this species.

Oxygen produced by the algae served to remove the small BOD remaining after activated sludge treatment, and led to an effluent high in dissolved oxygen. The effluent was clear and free from odor. A reduction in bacteria was noted in the pond. This matter is worthy of further investigation. Chlorination would be required to meet potable water standards although there are several alternative ways of re-using reclaimed waste water which do not require chlorination.

ACKNOWLEDGMENTS

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The assistance of Howard Goldner, Robert Parkhurst, Naomi Walloch, and B. H. Krishnamurty in analyzing samples is acknowledged. David Appleman in the Department of Irrigation and Soils contributed advice on algal growth in the initial phase of the study.

15 "The Effect of Algae on Selected Bacterial Population in Sewage," by G. B. Krishnamurty, Unpublished M. S. Thesis, Univ. of California, Los Angeles, Calif., June, 1959.

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DISCUSSION

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RUSSIAN WATER SUPPLY AND TREATMENT PRACTICES[a]

Closure by V. J. Calise and W. A. Homer

V. J. CALISE,[11] and W. A. HOMER.[12]—The writers are grateful to Mr. K. J. Ives for his pertinent comments on the Russian "biflow" or AKX filter, in which the draw-off pipe for filtered water is located in the upper layer of sand, and raw water enters the filter from the gravel base and from the sand surface with "biflow" established downwards through the top few inches of sand and upwards through the bulk of the graded bed.

While the writers knew of this application, they were not aware of the apparent frequency of its use. The data shown in Tables 5 and 6 indicate quite favorable results comparable to accepted normal filter-clarifier practice. However, nothing is mentioned of the long-range experience with clogging and collection with the internal collector design used. In addition, the problem of possible bypass of only partially-treated, partially-filtered water to the submerged internal collector is a point to be related to American sanitary practice.

[a] March 1960, by V. J. Calise and W. A. Homer (Proc. Paper 2407).
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FUNDAMENTAL CONSIDERATIONS IN HIGH RATE DIGESTION[a]

Closure by Clair N. Sawyer and Jay S. Grumbling

CLAIR N. SAWYER,[31] and JAY S. GRUMBLING,[32] A. M. ASCE.—The contributions made by Messers. Sulzer and Garrett relative to describing the kinetics of anaerobic digestion in terms of first order reactions is appreciated. There seems to be general agreement that the gross digestion process produces a net effect that can best be described by first order or monomolecular reaction kinetics.

In spite of the many assumptions made by Mr. Sulzer in his discussion, it is agreed that zero order reactions are involved in digestion and are responsible for a significant portion of the total changes occurring during anaerobic digestion. In order for zero order reactions to occur, however, it is generally accepted that substrate concentrations must exceed particular levels. Before concentrations reach and exceed these levels, or after they fall below these levels, the reaction proceeds in accordance with monomolecular behavior. Fig. 12 is presented to illustrate these phenomena.[33] It is therefore likely that the straight lines shown on Fig. 10, denoting individual removal and representing zero order reactions from start to finish, actually become curves as they approach the abscissa although the net effect would be essentially as Sulzer has indicated in the composite curve for overall removal.

Mr. Garrett has extrapolated the mathematics of first order reactions in light of known phenomena, to arrive at some interesting conclusions. By applying his Eq. 6b to published data, separate curves are developed in Fig. 11 for primary sludge and primary plus activated sludges. The order in which the curves fall is logical, but the rate constants derived do not seem consistent with the nature of the sludges undergoing digestion. The writers do not believe that the population of facultative bacteria in activated sludge is sufficient to cause the difference in rate constants. The rate constants derived from W. N. Torpey's[34] F. ASCE, work have been obtained from data on a series of studies with a single pilot unit being fed "mine run" sludges for extended periods of several months. Because these data were not obtained from parallel studies using identical sludges, this undoubtedly accounts for the considerable scattering of points plotted in Fig. 11. The normal variations in sludge character received in day to day operation at sewage treatment plants is considered sufficient basis to raise serious questions on the derivation of rate constants from

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[a] March 1960, by Clair N. Sawyer and Jay S. Grumbling (Proc. Paper 2411).

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[33] General Biochemistry, by J. S. Fruton and S. Simmonds, 2nd Ed., John Wiley and Sons, Inc., New York, 1958, p. 245.

[34] "Loading to Failure of a Pilot High-Rate Digester," Sewage and Industrial Wastes, by W. N. Torpey, Vol. 27, 1955, p. 121.

such data. The data from digesters being run in parallel would appear to provide a more valid basis for evaluating rate constants.

The writers do not agree with Mr. Garrett's interpretation of Eq. 12, "that the concentration of digestible volatile solids remaining is directly proportional to the displacement rate. . . ." Rather, they interpret the equation to mean that the concentration (or percentage) of digestible volatile solids remaining is proportional to the displacement rate as modified by the rate constant and independent of the concentration of the volatile solids in the feed. Two sludges with equal reaction rates will have essentially the same percentage of digestible solids remaining when operated at the same displacement rate, irrespective of the concentration of volatile solids in the feed. The writers see no disagreement with their findings and those of C. N. Sawyer and H. Schmidt[35] in studies involving the digestion of various sludge concentrations at definite detention times.

Sludge digestion is accepted to be a two stage process in which the second stage, involving the conversion of volatile acids and other simple derivatives

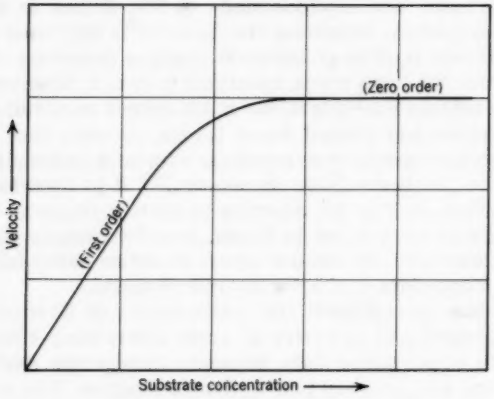

FIG. 12.—FIRST ORDER REACTION WHEN SUBSTRATE CONCENTRATION IS LIMITED AND ZERO ORDER REACTION WHEN SUBSTRATE CONCENTRATION EXCEEDS PARTICULAR LEVELS

of hydrolysis and oxidation-reduction to methane and carbon dioxide, is brought about by methane forming bacteria. From their limited observations of gas production from digesters batch-fed once daily, the writers are of the opinion that gas production is directly proportional to the bacterial population as long as the available substrate is plentiful and not inhibitory. The usual sequence of events immediately after batch feeding an operating digester is for the volatile acids content to increase, accompanied by an increase in gas production that reaches a maximum rate and remains at this rate until the volatile acid concentrations are reduced to normal levels. After volatile acids are reduced, gas yields become limited to, and directly related to the rate of volatile acid

35 "High-Rate Sludge Digestion," Journal, Boston Soc. Civ. Engrs., by C. N. Sawyer and H. E. Schmidt, Vol. 42, 1955, p. 1.

formation. Methane formation can therefore be considered a zero order reaction having the characteristics of the curve shown on Fig. 12. Due to the restrictions of the first stage of digestion in the first few hours after feeding, methane formation assumes the identity of a first order reaction and then behaves as a zero order reaction until again limited by substrate concentrations.

Mr. Keefer has pointed out some of the limitations of high rate digestion as regards internal mixing within a digester. His proposal to intimately mix raw and digested sludges in proper ratio before introducing fresh solids into a digester has merit and deserves continued study at other locations so that the practice can be evaluated on a wide variety of sludges.

OXYGEN BALANCE OF AN ESTUARY[a]

Closure by Donald J. O'Connor

DONALD J. O'CONNOR,[39]—Mr. Thoman is correct in stating that non-stratification has been assumed in both the lateral and vertical directions. These conditions are representative of both the James and Delaware Rivers over the section analyzed. The probable error, as determined from a statistical analysis of the cross-sectional data, does not necessarily represent any degree of stratification. Three of the ten sets of cross-sectional data of the Delaware River do indicate some lateral stratification, in the order of 0.5 ppm dissolved oxygen. The remaining seven sets indicate the variation is random and may not be assigned to a definite direction or elevation. It was therefore assumed lateral stratification was not significant. Mr. Thoman pointed out the sensitivity of Eq. 8 to the value of fresh water discharge and diffusivity. Further mathematical analysis and numerical computations have indicated the conditions under which the diffusivity is significant, the most important of which is the value of term d^2c/dx^2. At the point of inflection of the dissolved oxygen concentration curve, this term has a value of zero; in the vicinity of the inflection point, it has a low numerical value. It is for this reason that the values selected by Mr. Thomas gave similar profiles. The August profile of the Delaware and particularly the James River profiles are characterized by steeper second derivative curves and are more influenced by the value of diffusion coefficient.

In reference to the chloride profiles, Mr. McPherson questioned the reason "for using only the data for concentrations above, about 200 (as opposed to say 50 ppm). . . ." The chloride data used were those from Station 193 to Station 305 (Corps of Engineers) or from Station 21.18 to Station 0 (State of Delaware). This stretch was selected on the basis that there were no significant sources of pollution or dilution within this distance. Thus, there was nothing arbitrary about the use of chloride data (that is, 50 ppm versus 200 ppm as a minimum); the data were used consistently for the stretch under analysis. The values of the eddy diffusivity used in the computations, as requested by Mr. McPherson, are included in both Table 1 and in each figure showing the dissolved oxygen profile. The term "probable error" that is used in its strict statistical sense, defines a range of data from the 25 percentile to the 75 percentile. The parameter was used to define the variation of the data as shown on each figure and described in the paper. The term "fresh water inflow," as used by Messers. McPherson and Thoman, is more acceptable than the term "land runoff," as used by the writer.

Mr. Hull's objection to Eq. 21 is not directed toward the form of the relationship but the value of the coefficient. It appears from both theoretical con-

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[a] May, 1960 by Donald J. O'Connor (Proc. Paper 2472).

[39] Assoc. Prof. of Civ. Engrg., Manhattan College, New York, N. Y.

siderations and observed data that this equation is a reasonable difinition of the temperature dependency of the deoxygenation process. That the coefficient may not be 1.047 is generally acknowledged, but as Mr. Hull points out, in the approximate range from 15° to 30°, this value appears to be the best available. The writer[40] has also indicated from laboratory studies on aerated lagoons that the coefficient is 1.035 and the vast majority of reported values fall within the range of 1.030 to 1.060. The important point in this paper is that a consistent temperature dependency was incorporated into the development and use of this function permitted correlation of the available data of both BOD and dissolved oxygen profiles. In the majority of the studies with which the writer is either familar or associated, this value best fits the observed data. This criterion is far from, as Mr. Hull states, "placing unlimited confidence in self-purification computations based on this weak fundation." The writer does agree with Mr. Hull that further research is required in this respect.

The major points to which the discussions were addressed were as follows:

1. The assignment of the fresh water inflow rate.
2. The determination of the diffusivity.
3. The effect of photosynthesis.

In specific answer to the question raised by both Messers. McPherson and Thoman concerning the rate of fresh water inflow:

As stated in the section "Calculation of the Velocity Term," the rate of fresh water inflow was taken as the average value of a period of 2 weeks preceding the survey date. The discharge at Station 193 was computed by multiplying the average 2 week flow at Trenton by the ratio of the drainage area at Station 193 to that at Trenton. This ratio is 1.30, as compared to an approximate range of 1.2 to 1.4, as determined from the 10, 20 and 30 day average fresh water inflow values, given by McPherson in Table 4. The Trenton flows were obtained from the provisional records of the U. S. Geological Survey. The flow of the James River at City Point was obtained by adding the flows of the James at Richmond, the Appomattox at Petersburg, and Kanawha Canal near Richmond. The basis for determination of the fresh water inflow values was described in the paper, but it is reviewed herein in more detail in view of the questions raised by the discussion. The most significant point raised by both McPherson and Thoman concerns the time of travel from Trenton to the area under consideration, that ranges from approximately 10 days to 60 days. This factor was taken qualitatively into account by using the 2-week average, that was an arbitrary assignment. It appears a monthly average would be a more appropriate value for the August and October survey periods. It is significant, however, that the differences between the 10, 20, and 30 day averages of any one set are within about 20% as determined from Table 4, and that the differences among the sets are greater than this. The writer agrees that this is an extremely important factor and should not be disregarded in either tidal or non-tidal rivers. Mr. McPherson suggested the use of the existing hydraulic model to analyze both the steady and non-steady state of fresh-water inflow. The writer fully agrees that this approach may provide the data necessary to evaluate the contribution of fresh water inflow.

Mr. McPherson questioned the constancy of the diffusion coefficient and in reference to this point presented the salinity profiles obtained from the Delaware River model at Vicksburg. Over the total reach shown in Fig. 8, there

40 "Treatment of Organic Wastes in Aerated Lagoons," by D. J. O'Connor and W. W. Eckenfelder, Journal, Water Pollution Control Federation, Vol. 32, No. 4, April, 1960.

is no doubt that the diffusion coefficient is not constant. However, over the stretch under consideration in this paper, that is from Stations 193 to 305 the data indicates a reasonable constancy of this coefficient, as indicated in Fig. 9. In this figure, the orginal data are plotted rather than the curves, as shown in McPherson's Fig. 8. The data cover the range of flows from about 5000 cfs to 13,000 cfs that were used in the analyses of the oxygen balances. The straight lines defined by these data do indicate a constant value of the coefficient over the stretch under consideration, but obviously not of the entire estuary. The stretch over which the coefficient may be assumed constant is usually of sufficient length (about 20, miles to 25 miles) to cover the drop and subsequent rise in the dissolved profile. If, however, it is desired to define a profile under a steady state for a greater distance, then the analysis may proceed in stretches over which the coefficients are reasonably constant or a variable coefficient may be incorporated in the basic differential equations. The coefficients, computed by means of Eq. 16 for the data shown in Fig. 9 are plotted against fresh water inflow on logarithmic coordinates in Fig. 10. For comparison the values used in the oxygen analyses are also shown. These empirical relations indicate a relatively consistent trend for each set. However, the differences between sets, that is probably due to differences in prototype and model, is certainly a matter for further investigation. From the data on low-water slack, it appears that the value of the diffusion coefficient levels off as the flow increases. Similar data for the James River are also plotted in Fig. 10.

Mr. McPherson made reference to one of the writer's earlier publications[34] that provided the basis for Mr. Hull's simplified technique for determining the self-purification capacity. However, this technique does not obviate the need for determining the flow rate in either estuary or river. The location of the minimum dissolved oxygen is a function of both temperature and flow. It is the writer's firm opinion that elimination of time of flow is a desired and possible achievement, but oversimplification to the point of eliminating flow is both impractical and unrealistic. The fact is emphasized that flow provides not only dilution but is the primary factor in the location of the point of the minimum dissolved oxygen. Considering the extensive arguments presented to indicate the importance of flow, with which the writer agrees in principle, it appeared inconsistent in Mr. McPherson's discussion to suggest a technique that eliminated flow.

Mr. Hull's discussion is primarily concerned with the effect of photosynthesis. Most sanitary engineers, the writer included, are not unaware of the potential contribution of oxygen by photosynthetic activity. The impressive list of references as presented by Mr. Hull, attest to the awareness of this factor. Approximately one-half of these references were by engineers or presented in engineering journals, a significant portion of which dealt with algae effects.

If the inference may be drawn from Mr. Hull's discussion that photosynthesis is always a significant factor, then the writer disagrees. If, on the other hand, Mr. Hull is emphasizing the need to consider the possible effects of algae on the dissolved oxygen profiles, then the writer fully agrees. In view of the discussion, it is perhaps appropriate to comment on some of the negative aspects of this problem, tending to discount photosynthesis as a source of oxygen.

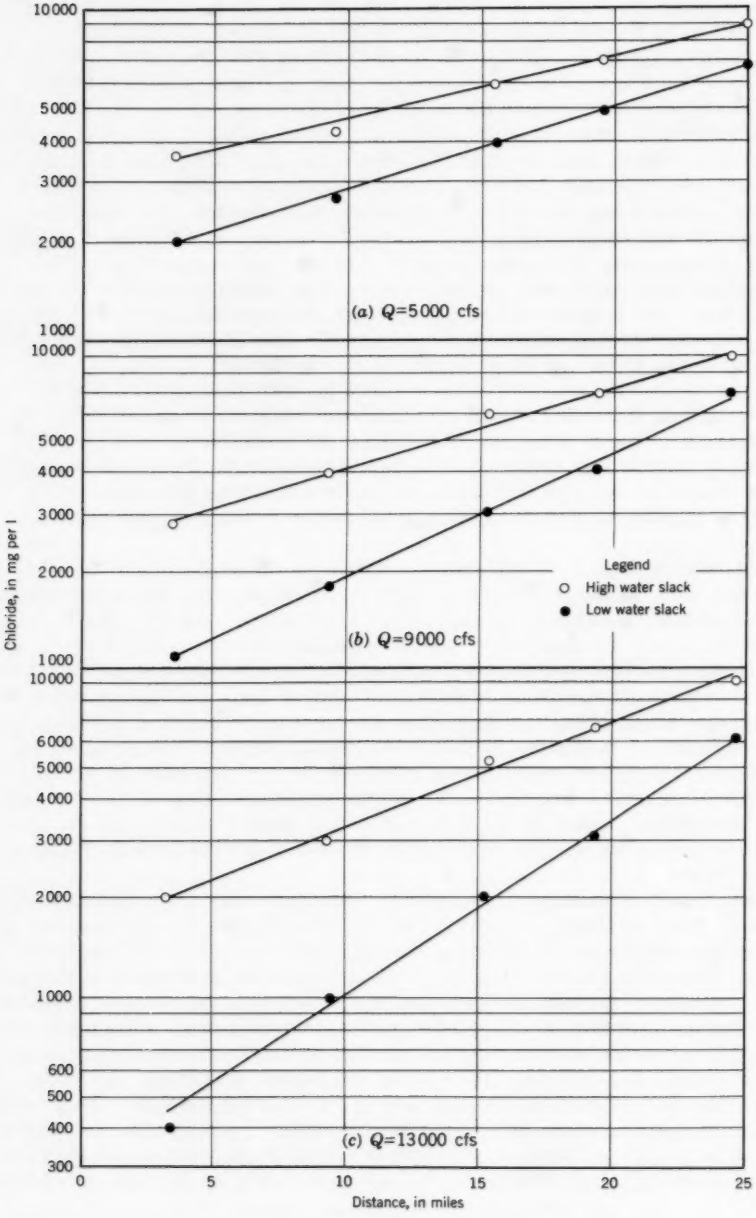

FIG. 9.—SALINITY PROFILES—DELAWARE ESTUARY

The basic requirements for algal growth are sunlight and nutrients. In regard to the latter, F. Ruttner[41] comments

> "investigations in plant physiology in recent years have shown that besides the ten known elements essential for the growth of plants - C, H, O, N, P, S, Ca, Mg, K, Fe - a considerable number of others not only stimulate growth but are also absolutely necessary although in inconceivably small amounts."

Temperature also has a profound influence on algal growths. It was reported[42] from a study of the Illinois River that "below 45° the plankton content of the Illinois River falls to about 9% of that present at higher temperatures."

The effect of turbulence, induced by winds, waves, or flowing water appear to have an inimical effect on growth. Numerous references are given in limnological tests. G. C. Whipple[42] states that

> "some microscopic organisms are extremely fragile and are readily broken up by agitation. Of these notably the filamentous algae develop well only in fairly quiet water. . . . . this explains why many forms of algae are not found in rivers. In the larger lakes and reservoirs wind and wave action are often sufficient to destroy or prevent microscopic growths."

A further significant quotation is "In flowing streams such production is usually not as important a factor in maintaining the presence of oxygen as is the

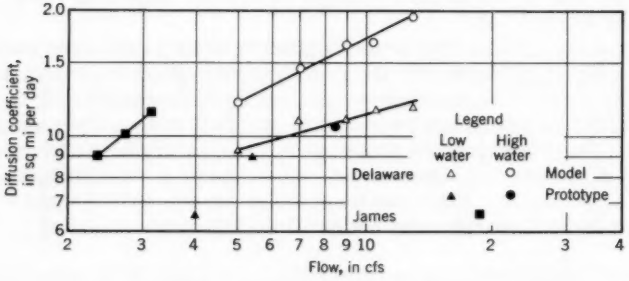

FIG. 10.—FLOW VERSUS DIFFUSION COEFFICIENT—DELAWARE AND JAMES ESTUARIES

solution of atmospheric oxygen. Turbulence and other physical conditions do not favor heavy growths of these heliphilous organisms." P. S. Welch[43] states

> "systems of streams, particularly those which do not drain standing-water units of any sort, usually yield small plankton crops. Many river systems, especially the swifter ones, have been reported as producing very little plankton compared with the standing waters into which they flow" and "that water currents above a very moderate speed are distinctly inimical to plankton development."

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41 "Fundamentals of Limnology," by F. Ruttner, Univ. of Toronto Press, 1953.

42 "Microscopy of Drinking Water," by G. C. Whipple, 4th Ed., John Wiley & Sons, New York, 1948.

43 "Limnology," by P. S. Welch, 2nd Ed., McGraw-Hill Book Co. Inc., New York, 1952.

In commenting on the communities of running water, Ruttner[41] says

> "A characteristic of clear-cut biological significance is the transport of water masses over great distances, even through contrasting climatic provinces, finally ending after a longer or shorter time with the emptying into the sea and the resulting death of most organisms carried along by the current. The duration of this transport, which is dependent on the length of the river and on the current velocity, determines whether or not there is the development of a true plankton biocoenosis - a potamoplankton. We can, indeed, capture plankton organisms with a net in many streams, particularly those containing lakes, ponds, or old river channels in their water sheds; but we do not know whether these plankton organisms are able to grow and reproduce under the altered conditions, or whether they are merely "tychoplankton" doomed to death. We can speak of a potamoplankton only when the prerequisite conditions for it have been provided, so that a special biocoenosis adapted to these particular conditions can be developed through selection of the species that are washed in. It can develop only in slowly flowing streams of great length, for example, the Volga, in which even the high water of spring requires almost two months to reach the sea. Within such periods of time, which are even longer in summer, the majority of plankton organisms find a sufficient range for the completion of their generations."

The age of the water is reported to have a definite bearing on plankton population. It has been noted by Welch[43] that "in the upper reaches of the Sangamon River, Illinois, water approximately 9 days old contained practically no plankton and that plankton did not begin to appear abundantly until the water was at least 20 days old."

One of the conclusions the writer wishes to draw from these references is that it is highly improbable that the photosynthetic effect is present at all times and in every river. The quantitative estimation of photosynthesis by the light-and-dark bottle technique are reported by Mr. Hull inherently possesses a distinct limitation. The quiescent condition in a laboratory bottle is one that tends to promote algal activity. By contrast, the currents in natural bodies of water tend to be destructive. Thus, the increase in oxygen due to algae in the incubated and quiescent sample may not at all be indicative of actual conditions in the river.

In order to evaluate the oxygen contribution by algae, it is necessary to sample hourly for dissolved oxygen. The diurnal variation of dissolved oxygen is the best indication of this factor. Examples of such data is shown in Fig. 11 for Codorus Creek on different sampling periods. From these data, it may be concluded that the algae, if present, are not significantly contributing to the oxygen supply. By contrast, the data from the Wabash River as shown in Fig. 11 indicates the marked effect the algae have on the dissolved oxygen levels.

Mr. Hull presented data showing supersaturated dissolved oxygen concentrations in the Delaware. None of the examples presented are the same in time or place, as those used by the writer. As a matter of fact the data of 1956, reported by Kaplovsky, indicate no supersaturated values at any station during any survey, for both the corss-sectional series and the same slack series. In other words, there was no indication of algae effects and therefore, no consideration was given to it. The data referred to by Mr. Hull undoubtedly do reflect the photosynthetic effect, but they would not be appropriate to use in check-

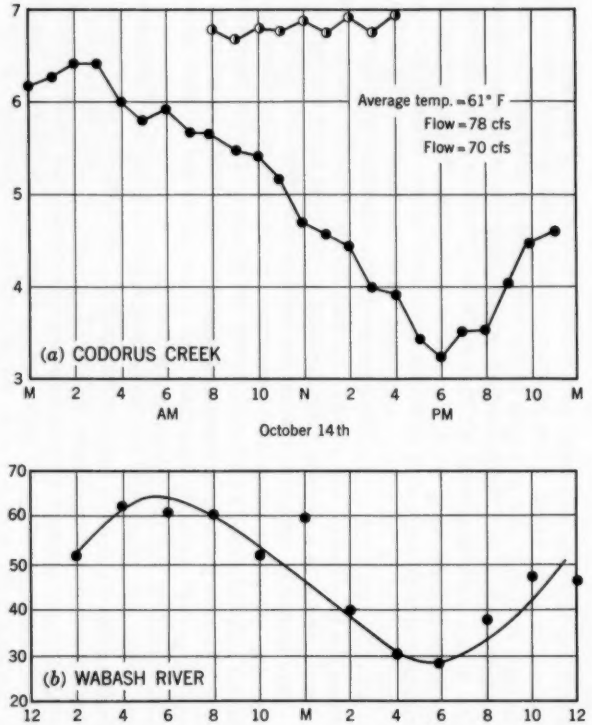
Average temp. = 61° F
Flow = 78 cfs
Flow = 70 cfs
(a) CODORUS CREEK
M 2 4 6 8 10 N 2 4 6 8 10 M
AM
PM
October 14th
(b) WABASH RIVER
12 2 4 6 8 10 M 2 4 6 8 10 12

FIG. 11.—DIURNAL DISSOLVED OXYGEN VARIATION

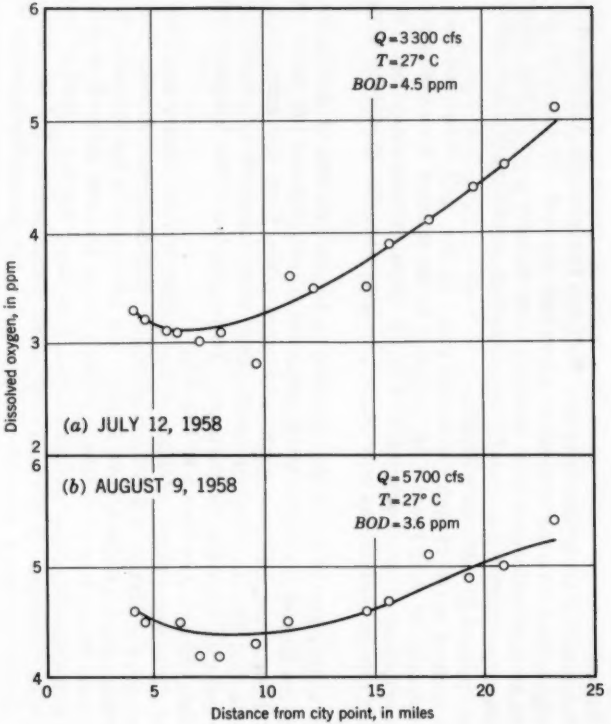
Q = 3300 cfs
T = 27° C
BOD = 4.5 ppm
(a) JULY 12, 1958
(b) AUGUST 9, 1958
Q = 5700 cfs
T = 27° C
BOD = 3.6 ppm
Dissolved oxygen, in ppm
Distance from city point, in miles

FIG. 12.—DISSOLVED OXYGEN PROFILES, 1958

ing an hypothesis that does not include algae effects. This was not the purpose of the paper.

In conclusion if there is evidence to indicate the presence and effectiveness of the algae, then this factor must be taken into account. On the other hand, if there is no such evidence, it is unrealistic to assume a priori that algae are significant, particularly in view of the number of conditions that are necessary for their proper growth and activity.

The factors in the oxygen losses and gains as Mr. Hull presented them, are automatically, or may readily be, included in the present formulations either in the evaluation of the coefficients or in the actual stream sampling. The sulfate and nitrate reductions only come into play when the dissolved oxygen is zero.

The writer recently had the opportunity to analyze data of additional surveys on the James River that were conducted at both high and low water slacks. The values of the diffusion coefficient were taken from the extrapolation as shown in Fig. 10 and the other coefficients were computed in accordance with the procedures described in the paper. Two examples of the computed profiles and observed data are shown in Fig. 12.

The dissolved oxygen profiles of the Hudson River estuary and New York Harbor were analyzed in a fashion similar to that described herein. The fresh water discharge into New York Harbor was estimated in the following fashion: the Hudson River flow at Mechanicsville and the Mohawk River flow at Cohoes were added and the sum multiplied by 1.2 to allow for the tributary drainage below these stations. It had previously been estimated that for the mean summer condition it takes approximately a month for the Mechanicsville flow to reach the New York City line. Therefore a lag of 30 days was assumed between these two locations; for example, the upstream flow of July was associated with the August survey data. Because of the limited number of samples that were collected at the same slack time, average values of the monthly periods were used in this analysis. An example of the computed profile and the observed data is shown in Fig. 13. The procedure of assigning the fresh water discharge is more in line with Messers. McPherson's and Thoman's discussions. It is also pertinent to note, in view of Mr. Hull's discussion, that a limited number of samples indicated saturated or super-saturated values in the upstream area at the city line that is relatively unpolluted. Because less than 5% of the Hudson River data indicated a possible photosynthetic effect, no attempt was made to account for this factor separately. As both Mr. McPherson and Mr. Thoman appreciated, there is a certain arbitrariness in drawing a line through a set of data. This factor is minimized when the coefficients thus determined may be correlated to a distinct independent function. In the case of the deoxygenation coefficient this function is the temperature relationship; for the reaeration coefficient it is both the temperature and velocity relationship; in the case of the velocity, it is the continuity equation; and some empirical relation appears to exist between flow and the diffusion coefficient.

Also, when one considers the interrelationship among the various coefficients, the arbitrariness is further minimized. Although one set of coefficients may define the dissolved oxygen profile of one set of data, these coefficients correlated to other temperatures, flow and tidal conditions must then define the dissolved oxygen profiles of other sets. There is, therefore, a consistency from one step to the next for each set of data and furthermore, a consistency in the coefficients among the various sets of data. Thus, the final curves came

as a result of many trials and all coefficients used in computation of these curves were consistent within the framework of the basic relationships. Mr. Hull in his conclusion referred to the application of computers to the solution and analysis of this problem. The writer suggests that the formulation of the equation must in all cases proceed the use of the computer. The problem does not lie, as Mr. Hull states, in the refusal of engineers to accept and to understand all the factors that influence the dissolved oxygen profile; it is, rather, in our

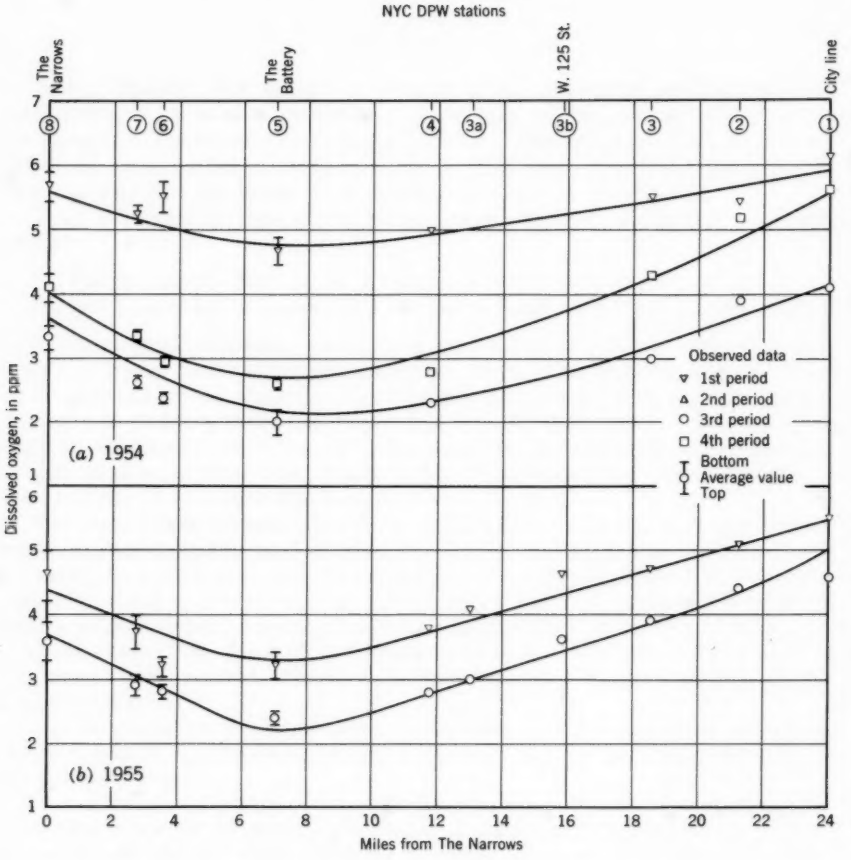

FIG. 13.—DISSOLVED OXYGEN PROFILES OF HUDSON RIVER AND UPPER HARBOR

inability to construct appropriate mathematical models to define the natural phenomena that influence the profile and in our inability to express the interrelationship among these factors mathematically. When and if these ends are accomplished, the machines for both solution of the equations and analysis of data are available. But first and most important are the equations themselves. It is to this end that this paper was directed.

INVESTIGATION OF THE CORROSIVE BEHAVIOR OF WATERS[a]

Discussion by James Girand

JAMES GIRAND,[3] F. ASCE.—Corrosion is one of the most serious problems confronting water system operators. Conditions will become more critical as the pipelines become older and loads increase. The general practice of overdesigning distribution systems to allow for fire protection has created a surplus capacity that has masked the deterioration due to corrosion.

From the point of view of the water works operator, corrosion takes two forms:

1. Tuberculation, that causes a reduction of carrying capacity; and
2. Iron pickup in the water, that results in "red water" and laundry stains.

Tuberculation frequently calls for a continuous program of main cleaning. Even a company as small as Elizabethtown Water Company has spent as much as $15,000 per yr for cleaning. Some plants must clean twice a year. The alternative to cleaning is the construction of new parallel mains. If tuberculation could be eliminated, the savings to the water industry would be incalculable.

Customer complaints from red water lead to unsatisfactory public relations. The problem of red water has been fairly well solved.

For many years the writer has been engaged in a continuing program of corrosion research at the local plant level. Due to limited funds, personnel, and facilities, this work could not be performed on the scale or with the thoroughness described in the paper. In spite of these years of research, it must be frankly admitted that no answer has been found. The paper cites 25 papers by eminent authorities. Most of these have been studied carefully, but in spite of this mass of information, tubercles continue to grow and flaunt the best efforts to control them.

It is the writer's conclusion that much still remains unknown about the causes and particularly the cures of corrosion and that many of the "well known facts" are not facts at all.

In an effort to develop some correlation between different types of water and corrosion rates, the laboratory work described herein was performed. Thirty-five separate waters were analyzed; fourteen of these were natural waters from surface or well sources, and 21 were synthetic waters. An effort was made to cover a broad spectrum of analyses in an effort to determine or not some correlation between the chemical constituents and the rate of corrosion could be discovered. It must be stated that these results were practically all negative. No correlation could be found except an important group of waters in which the pH was around 10.5.

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[a] November 1960, by Werner Stumm (Proc. Paper 2657).

[3] Chf. Engr., Elizabethtown Water Co. Consol., Elizabeth, N. J.

Experimental Method.—The writer's experimental methods are practically identical with those of the author except they were conducted on a much lower scale due to lack of funds and facilities. Corrosion measurements were made on approximately 7.3 cm by 1.6 cm by 0.35 cm samples of cast iron cut from standard cast iron pipe. The specimens were ground, polished, and degreased prior to the immersion into the test water.

The specimens were immersed in a 5-gal jar of the test water and stirred continuously for 48 hr. The chemical analysis of the waters used are given in Table 3. The water was analyzed before and after the test in order to determine the amount of iron taken by the solution. After 48 hr of stirring, the corrosion products were carefully removed and the specimen reweighed on a precision balance to determine the weight of iron lost. Apparently the loss of weight could be ascertained with extreme precision.

Corrosion Rates.—All of the tests were made for exactly 48 hr immersion and the loss of weight and iron pickup in the water determined for that period of time. This corresponds to the author's method of determining the initial corrosion rate. The writers techniques did not permit the ascertaining of corrosion rates for extended periods of time.

The results of these tests are shown in Table 3.

Table 3(I) shows the chemical composition and corrosion characteristics of the natural waters investigated. Table 3(II) shows the same information for the synthetic waters.

As it is the commonly accepted belief that pH, alkalinity and calcium are the most pertinent factors which affect corrosion, these figures have been plotted on six charts in an effort to detect any visible correlation.

Fig. 8, 9 and 10 show the loss of weight of the iron specimens as related to pH, alkalinity and clacium. Of these three charts, Fig. 8, relating to the loss of weight versus pH, is the only one that shows any apparent correlation. The relationships between loss of weight and calcium, and loss of weight and alkalinity appear to be non-existent.

Figs. 11, 12, and 13 show a plotting of the increase of iron in solution as related to the pH, alkalinity and calcium of the 35 water samples tested. From Fig. 11, there appears to be some visible correlation between pH and increase of iron in solution in that pH levels about 9.0 appear to produce the least amount of iron pickup. There appears to be no correlation whatever between iron pickup and calcium or alkalinity.

Natural Waters.—Actual observations of the conditions of the interior of the cast iron mains in the distribution systems have been made for certain of these natural waters. Sections of pipe that have been in the ground more than 50 yr have been removed and examined. It was also possible to observe the condition of the interior of the pipe by examining the coupons cut from pipe when tapping sleeves were installed. From these actual observations of pipe which has been in service more than 50 yr the following results were noted:

Sample 1: Lake Otisco, New York.—This is known as a "miracle water." Unlined cast iron pipe after 50 yr of service shows no observable corrosion.

Samples 9, 10, and 11: From wells in the vicinity of Elizabeth, New Jersey.—Unlined cast iron pipe that has carried water from these wells shows only a few scattered tubercles, that however, are of considerable size. The water must be classified as practically non-corrosive.

Samples 2 to 6: The surface water from the Raritan River is highly corrosive. All efforts to reduce the corrosiveness of this water have failed. Every

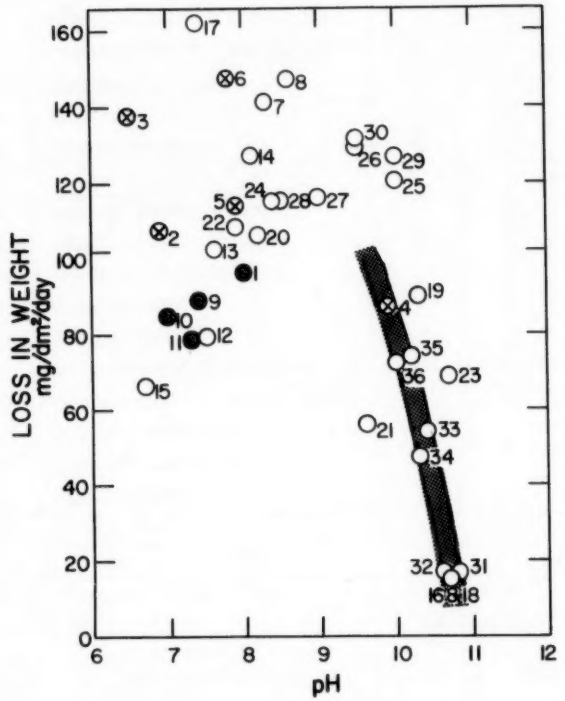
LOSS IN WEIGHT
mg/dm²/day
pH

FIG. 8

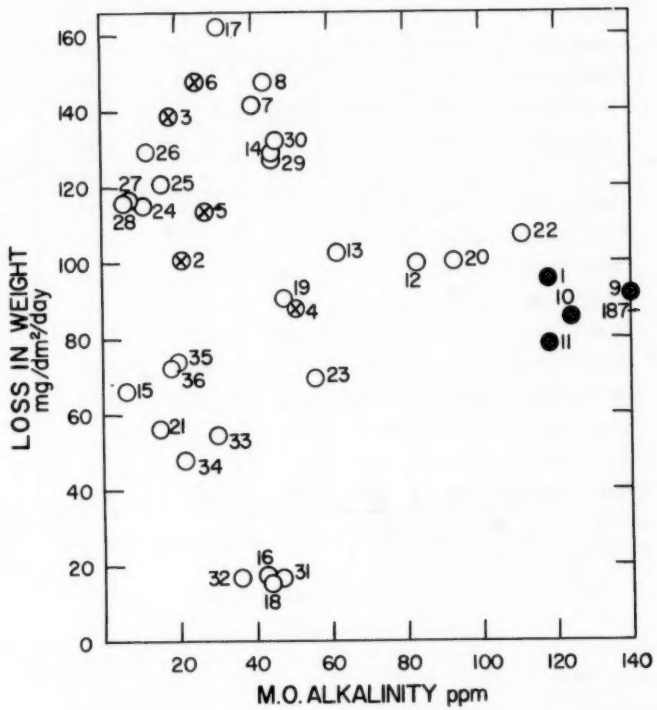
LOSS IN WEIGHT
mg/dm²/day
M.O. ALKALINITY ppm

FIG. 9

TABLE 3.—CHEMICAL COMPOSITION AND CORROSION CHARACTERISTICS OF WATERS INVESTIGATED

Sample No.	Waters Investigated	P. Alk.	MO Alk.	DO	Ca	Cl_2	pH	Results after 48 Hours Immersion		Appearance of test specimen
								Increase of Fe in solution	Corrosion rate mg per dm^2 per day	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
I. NATURAL WATERS										
(a) Surface waters										
1	Lake Otisco, N. Y.	0	118	13.0	38.4	0.0	8.0	0.27	95.7	Heavy Rust
	Raritan River, N. J.									
	E'town Filter Plant									
2	Raw Water	0	21	12.7	13.6	0.0	6.9	0.8	107.8	Heavy Rust
3	Basin Inlet (Alum added)	0	18	13.0	12.8	0.0	6.5	0.5	138.25	Heavy Rust
4	At Lime Header	18	55	13.1	26.4	1.3	9.9	1.05	87.8	Heavy Rust
5	Basin Outlet	0	27	12.9	16.8	0.9	7.9	1.25	113.80	Heavy Rust
6	Filtered Delivered Water	0	25	12.9	17.6	0.62	7.8	1.3	147.85	Heavy Rust
7	Filtered Delivered Water	0	40	10.7	21.6	0.8	8.3	0.28	141.5	Heavy Rust
8	Filtered Delivered Water	0	43	10.7	23.2	0.8	8.6	0.30	147.4	Heavy Rust
(b) Well waters and mixtures										
9	Hummocks Wells	0	187	7.2	90.4	0.15	7.4	1.0	91.75	Light Rust
10	Springfield Wells	0	124	8.3	58.4	0.15	7.0	1.5	85.7	Light Rust
11	Greenbrook Wells	0	118	3.5	182.4	0.0	7.3	1.8	78.7	Light Rust
12	50% Greenbrook - 50% Raritan	0	83	6.1	103.2	0.3	7.5	1.2	79.8	Light Rust
13	25% Greenbrook - 75% Raritan	0	62	7.2	57.6	0.45	7.6	0.7	102.3	Heavy Rust
14	100% Raritan	0	45	8.0	25.6	0.75	8.1	0.6	127.7	Heavy Rust

II. DISTILLED WATER SYNTHETICS

(c) Distilled water with following additives:

15	Distilled Water Only	0	6	8.9	0.0	0.0	6.7	0.3	66.7	Heavy Rust
16	30 ppm NaOH	33	43	8.9	2.4	0.0	10.7	0.01	15.7	No Rust
17	5 ppm Phosphate	0	31	13.5	16.8	0.65	7.4	3.0	162.4	Heavy Rust
18	30 ppm CaOH	30	44	9.1	16.0	0.0	10.7	0.03	15.8	No Rust
19	40 ppm $NaCO_3$	21	47	8.9	0.8	0.0	10.3	0.4	90.33	Light Rust
20	150 ppm Na_2HCO_3	1	93	8.8	0.8	0.0	8.2	0.5	105.32	Heavy Rust
21	35 ppm Silica	10	15	8.6	0.0	0.0	9.6	0.2	56.25	Rust Spots
22	82 ppm CaOH + CO_2	0	112	8.3	38.4	0.0	7.9	0.5	107.4	Heavy Rust
23	30 ppm CaOH + 1 ppm Cl_2	37	56	9.1	14.4	1.0	10.7	0.8	69.25	Rust Streaks
24	82 ppm CaOH + 31 ppm H_2SO_4	1	11	8.9	36.8	0.0	8.4	3.0	115.49	Heavy Rust
25	10 ppm CaOH	5	16	8.2	3.2	0.0	10.0	0.25	120.82	Rust Streaks
26	5 ppm CaOH	2	12	8.9	1.6	0.0	9.5	0.45	129.59	Rust Streaks
27	3 ppm CaOH	2	7	8.7	0.0	0.0	9.0	0.5	116.1	Rust Streaks
28	2 ppm CaOH	1	6	8.5	0.0	0.0	8.5	0.5	115.65	Rust Streaks
29	30 ppm CaOH + CO_2	12	45	8.6	12.8	0.0	10.0	0.15	127.05	Rust Streaks
30	30 ppm CaOH + CO_2	8	46	8.6	14.4	0.0	9.5	0.2	132.05	Rust Streaks
31	30 ppm CaOH	36	47	8.5	16.0	0.0	10.8	0.1	16.5	No Rust
32	20 ppm CaOH	22	36	8.5	11.2	0.0	10.6	0.15	16.8	No Rust
33	15 ppm CaOH	17	30	9.0	8.8	0.0	10.4	0.15	54.5	Rust Streaks
34	10 ppm CaOH	11	21	8.8	6.4	0.0	10.3	0.1	47.7	Rust Streaks
35	7.5 ppm CaOH	10	20	9.0	4.0	0.0	10.2	0.25	74.01	Rust Streaks

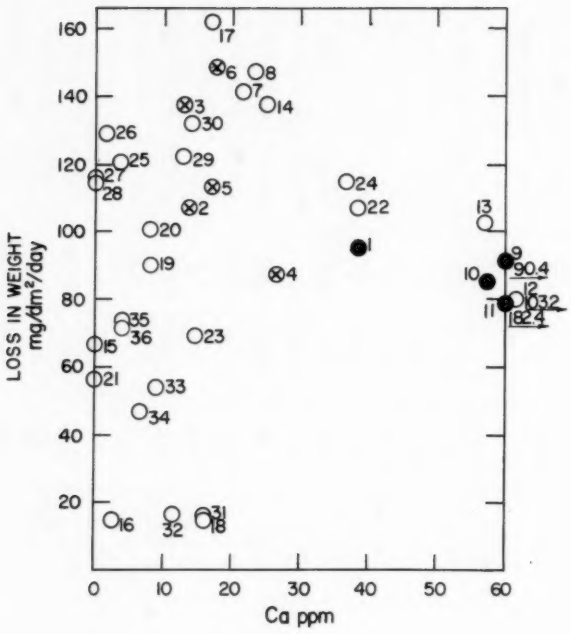
LOSS IN WEIGHT
mg/dm²/day
Ca ppm
0
10
20
30
40
50
60
20
40
60
80
100
120
140
160

FIG. 10

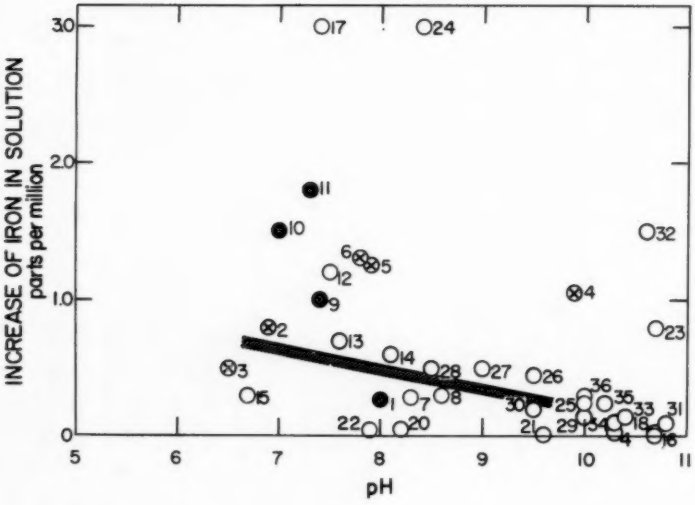
INCREASE OF IRON IN SOLUTION
parts per million
pH
5
6
7
8
9
10
11
0
1.0
2.0
3.0

FIG. 11

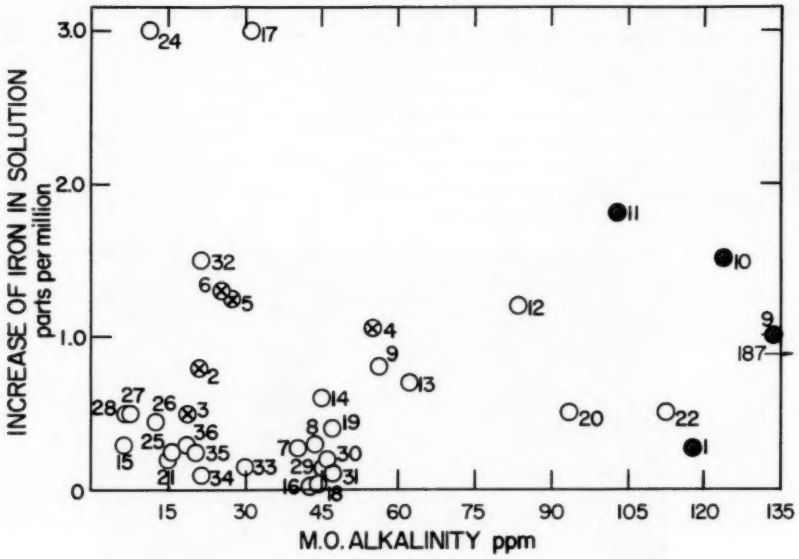
INCREASE OF IRON IN SOLUTION
parts per million
M.O. ALKALINITY ppm
3.0
2.0
1.0
0
15
30
45
60
75
90
105
120
135

FIG. 12

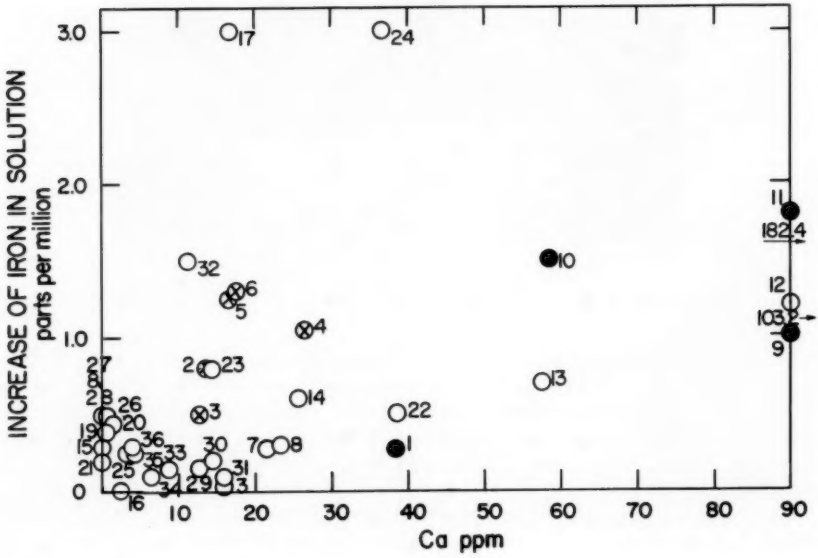
INCREASE OF IRON IN SOLUTION
parts per million
Ca ppm
3.0
2.0
1.0
0
10
20
30
40
50
60
70
80
90

FIG. 13

effort has been made on a plant scale to produce a stable water by the addition of lime, soda ash, and other alleged inhibitors - but without encouragement. The techniques described in the various papers listed in the author's bibliography have been tried with little success.

The standard operating procedure is to maintain a delivered water that should be stable and with a Langlier Saturation Index above zero. Figs. 14 and 15 show the results. Fig. 14 shows corrosion after 1 yr in water with Saturation Index approximately zero. The specimen shown in Fig. 15 had been immersed for 7 days in water with a zero saturation index. Heavy corrosion has appeared in this short time. These are cast iron specimens that were inserted in a main

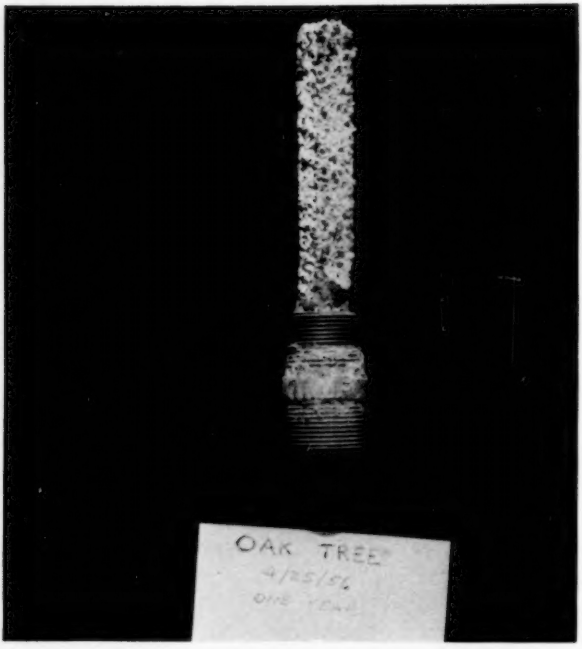

FIG. 14.—CAST IRON SPECIMEN INSERTED IN MAIN UNDER PRESSURE

with a standard tapping machine. These specimens are prepared from standard cast iron pipe, as are the threaded holders, so no electrolytic action can occur. In spite of the chemical additives that should produce a stable water, it is seen that after a year's immersion extensive tuberculation has occurred. This tuberculation is so rapid that it will reduce the coefficient of newly cleaned pipe from C = 120 to a level of C = 80 in about three months time.

Another technique used by the writer in the laboratory is shown in Fig. 16. Cast iron specimens are placed in a glass tube for observation and to eliminate any electrolytic action. Water is allowed to flow continuously. In spite of the efforts to maintain a stable water, corrosion is rapid.

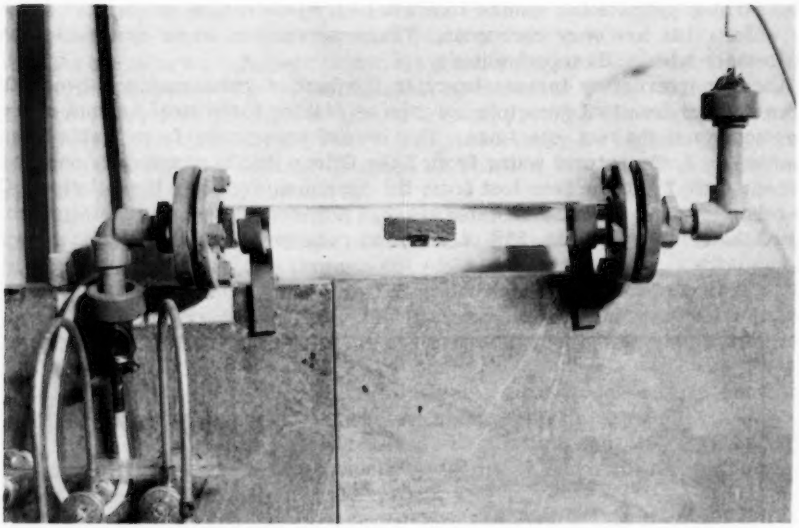

FIG. 15.—LABORATORY EQUIPMENT TO OBSERVE CORROSION OF CAST IRON SPECIMEN IN FLOWING WATER

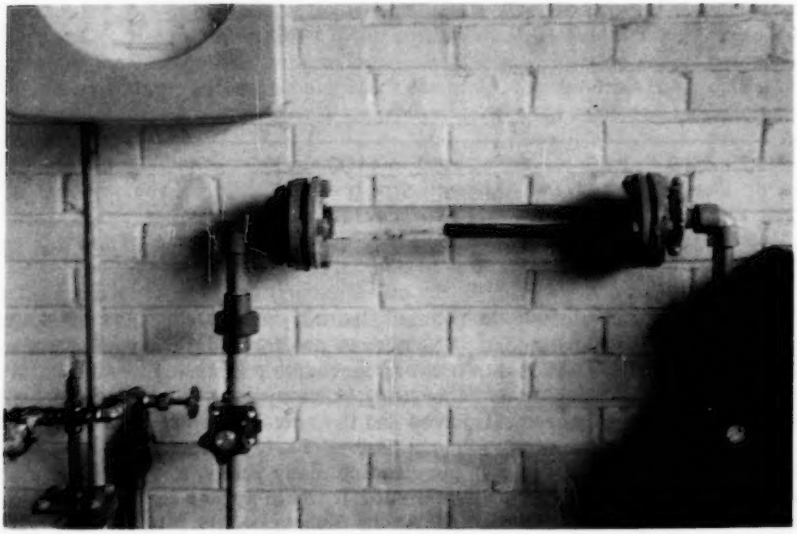

FIG. 16.—GLASS PIPE WITH CAST IRON SPECIMEN USED TO OBSERVE CORROSION RATE IN FLOWING WATER

To point out the lack of correlation between laboratory work and the actual observations of pipe more than 50 yr old, the various charts have been marked. Solid circles indicate the waters known to be non-corrosive, and an "X" marks the waters that are very corrosive. There appears to be no correlation between these widely divergent waters.

Another interesting inconsistency is the lack of relationship between the percentage of iron that goes into solution as related to the total amount of iron removed from the test specimen. The lowest percentage from Table 3 was sample No. 1, the natural water from Lake Otisco that is practically non-corrosive. Only 7% of the iron lost from the specimen went into the solution. On the other hand, in the case of water No. 8, a non-corrosive natural water from one of the Elizabeth wells, 55% of the iron removed from the specimen went into solution.

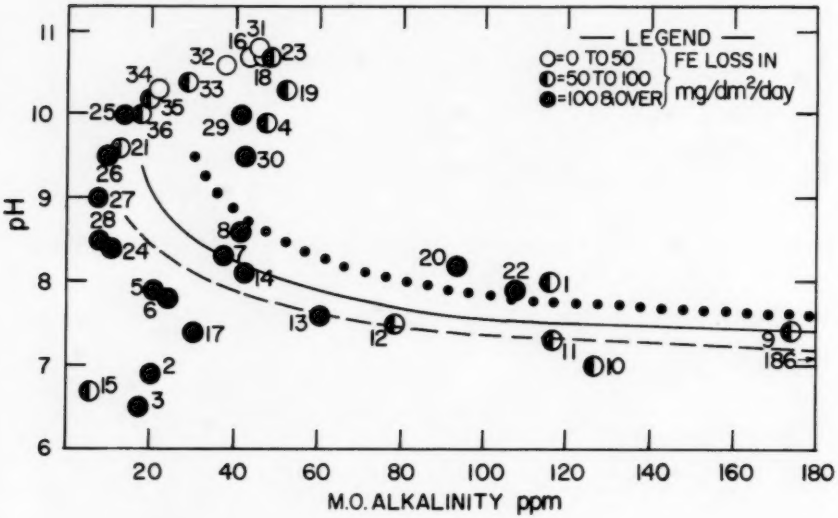

FIG. 17

Fig. 17 is a chart plotting the pH and alkalinity against the measured loss of weight of the iron specimens. The curves are the widely accepted curves allegedly showing the relationship between corrosive and non-corrosive waters. From the results obtained in the laboratory, there appears to be no relationship whatever between the theoretical curves and the actual measured loss in weight.

From an examination of the various plotted charts, coupled with the observations of pipe which has been in service for many years, and also in view of the various papers that have been published, it would appear that the first conclusion to be reached is that our laboratory techniques are faulty. The writer will be the first to concede the deficiencies in his techniques. However, considering that thirty-five separate waters of such widely differing characteristics were examined, it would appear that in spite of the shortcomings of the method, some correlation could be found.

It is the writers considered conclusion that there must be some factors that have not been discovered as yet. Specifically, there must be some inhibitors or accelerators of corrosion in the natural waters. If an inhibitor could be found it would be a godsend to the water works industry.

The author is to be commended for his painstaking and thorough efforts as set forth in his paper. The operating staff of the water works industry would like to do everything possible to encourage and promote the efforts of these researchers. The American Water Works Association is organizing a committee on research, the primary purpose of which is to assist and encourage work such as that done by the author.

Through some such organization as the American Water Works Association a nation-wide study could be made of corrosive and non-corrosive natural waters. There is no doubt that through the AWWA, or acting as individuals, the major United States water supply organizations would co-operate enthusiastically in such a research program. If the author and other researchers in the field would call on the local plants for co-operation, it would be most promptly and generously given.

One of the first objectives would be to develop a simple laboratory technique to evaluate the corrosiveness or non-corrosiveness of any particular water. If such a standard laboratory procedure could be promulgated, the operating filter plants throughout the country would be willing to make these routine tests and report them to the central organization.

A second, and perhaps the most important, problem is that of obtaining factual observations of the action of the corrosive and non-corrosive waters on cast iron pipe. The writer's technique of inserting a cast iron specimen into a main with a tapping machine offers an opportunity to make an accelerated observation of the corrosiveness of the water.

A high degree of objectivity must be established. To prove a conclusion, it is necessary that the corrective measures produce a certain result. It is then necessary that the corrective measures be withdrawn and the conditions return to the prior status. Without rounding out the proof, the results are inconclusive. Wishful thinking may often play a large part in what is reported as conclusive results.

What is needed is a finite measure of the results obtained. Visual observations can be made with the inserted specimens as previously outlined, by observing pipe removed from the system, or by observations of the cuts made when tapping valves are inserted.

Even more valuable observations can be made when it is possible to measure the coefficient of a long transmission main before and after cleaning. There are undoubtedly a number of large water systems that practice main cleaning on a routine basis and who have the technical staff capable of making precise observations. By obtaining the co-operation of such plants, various research projects could be undertaken with a higher level of conclusive results.

DERIVATION OF FLOW EQUATIONS FOR SEWAGE SLUDGES[a]

Discussion by George Bugliarello

GEORGE BUGLIARELLO,[17] A. M. ASCE.—The following remarks are offered with the hope of furthering the usefulness of Mr. Behn's paper, both by extending its scope and by discussing the limitations of some of the concepts, when they are applied to actual situations.

There is an important category of time-independent flows that do not follow Eq. 5. Such are, for example, flows in which appreciable phase separation takes place.[18]

The exponential form for pseudo-plastic fluids is the equation of a line that fits a portion of their log τ versus log (du/dy) diagram. The usual shape of one of such diagrams is shown in Fig. 1, that indicates that in reality a single straight line does not fit the extremes of the range in τ values. Hence, integration of Eq. 3 to yield the overall relationship between flow rate and pressure drop in a conduit must be performed either by using different values of n and K for different portions of the radius of the conduit - an onerous procedure - or by using for n and K the values giving the best fit in the region of the conduit that is of importance (that is, for a pipe, at the higher stresses prevailing in the peripheral region, rather than in the region around the center line, that contributes little to the overall discharge). As a result Eqs. 50, 82, and 83 that are derived on the assumption of a single value of n and K for the cross-section, are not rigorous. They have been shown to be sufficiently accurate in many cases, but extrapolations to fluids for which the rheological diagram is not known over the whole range of shear stresses acting along the radius, should be made carefully. The more so, because published tabulations of the values of n and K seldom give the range of τ for which such values are valid.

More rigorous and, also of course, more general than Eqs. 50, 82, 83 is Eq. 75, that is based on the actual values of the shear stress as the wall, τ_w and not on the integration of an expression of partial validity. However, even Eq. 75 may lead to serious error when applied to complex time-independent flows that do not follow[19] Eq. 4.

The consideration of the departure of the rheogram for pseudo-plastics from a straight line at extreme values of the shear stresses becomes particularly important when the analysis of the laminar regime has the purpose of obtaining a basis for the prediction and correlation of the turbulent regime.

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[a] November 1960, by Vaughn C. Behr (Proc. Paper 2663).

[17] Asst. Prof. of Civ. Engrg., Carnegie Inst. of Tech., Pittsburgh, Pa.

[18] "A Particular Non-Newtonian Flow," by J. W. Daily and G. Bugliarello, Ind. and Eng. Chemistry, Vol. 51, No. 7, July, 1959.

[19] "The Effects of Fibers on Velocity Distribution, Turbulence and Flow Resistance of Dilute Suspensions," by J. W. Daily and G. Bugliarello, Technical Report 30, MIT Hydrodynamics Lab., October, 1959.

Ultimately, in turbulence, energy is dissipated by the laminar friction experienced by small scale vortices. Hence, the average shear stresses acting on these vortices should determine the region of the rheogram to be used in deriving the values of the rheological indexes n and K which characterize the non-Newtonian viscosity and figure in a generalized Reynolds number such as that of Eq. 129. When these indexes differ significantly from the values that are of importance in determining the pressure discharge relationship for laminar flow, a correlation for turbulent flow based on the latter values may be less satisfactory.

If sufficiently high rates of shear are reached, the flow may become turbulent. Because this is the more common type of flow likely to be encountered in sanitary engineering practice even with rather viscous non-Newtonians, it is pertinent to review briefly the information available for the turbulent regime.

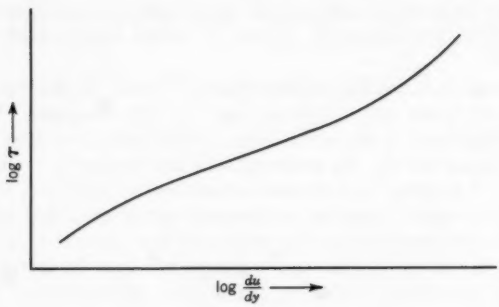

FIG. 1

For the prediction of the mean flow characteristics in turbulent flow, D. W. Dodge and A. B. Metzner[20] established a correlation on rational grounds between friction losses and turbulent velocity profiles, that leads to a dimensionless velocity profile expressed by Eq. 159.

$$\frac{u}{\sqrt{\tau_w/\rho}} = \frac{5.66}{(n')^{0.75}} \log \frac{y^n (\sqrt{\tau_w/\rho})^{2-n} \rho}{K}$$

$$- \frac{0.40}{(n')^{1.2}} + \frac{2.458}{(n')^{0.75}} \left[1.960 + 1.255\, n' - 1.628\, n' \log \left(1 + \frac{3}{n'} \right) \right] \quad \ldots\ldots (159)$$

and to a friction factor f expressed by Eq. 160.

$$\frac{1}{\sqrt{f}} = \frac{4.0}{(n')^{0.75}} \log \left[N_{RE}\, (f)^{1 - \frac{n'}{2}} \right] - \frac{0.40}{(n')^{1.2}} \quad \ldots (160)$$

[20] "Turbulence in Non-Newtonian Systems," by D. W. Dodge and A. B. Metzner, Dept. of Chem. Engrg., Univ. of Delaware, Newark, Del., February, 1958.

In Eqs. 159 and 160, n, n' and K are the rheological indexes obtained from the laminar flow rheograms. The term K is related to K' by Eq. 77 and n to n' by Eq. 161.[21]

$$n = \frac{n'}{1 - \frac{1}{3n' + 1} \frac{d\, n'}{d \log \tau_w}} \quad \ldots\ldots\ldots\ldots\ldots \quad (161)$$

that, when n' does not vary with τ_w, yields n = n' (this is a common occurrence as pointed out by the author). The term N_{RE} is the generalized Reynolds number of Eq. 129.

For a Newtonian flow (n = n' = L and K = μ), Eq. 159 reduces to the familiar semilogarithmic law for turbulent flow in smooth pipes:

$$\frac{u}{\sqrt{\tau_w/\rho}} = A \log \frac{y\sqrt{\tau_w/\rho}}{\nu} + B \quad \ldots\ldots\ldots \quad (162)$$

with values of the constants A and B respectively equal to 5.66 and 5.1, close to the established values of 5.75 and 5.5. Similarly Eq. 160 reduces to

$$\frac{1}{\sqrt{f}} = C \log \left(N_{RE} \sqrt{f}\right) - D \quad \ldots\ldots\ldots \quad (163)$$

with C and D equal respectively to 4.0 and 0.40, in agreement with Nikuradse's values.

Eq. 159 and 160 are generally in agreement with the available experimental evidence, when applied to pseudoplastic fluids, as well as to fluids following the more general Eq. 4. For fluids that do not fall within these categories, however, Eqs. 159 and 160 do not apply,[19] and there is no substitute as of now for empirical data, that cannot be safely extrapolated even to the same fluid flowing in channels of different dimensions.

For flows following Eq. 3 and, more generally, Eq. 4, the end of the laminar regime in circular tubes occurs, as expected, for a value of the generalized Reynolds number that is approximately the same as for Newtonian flow. However, if the flow does not follow Eq. 4, different criteria, varying from case to case must be used in predicting the beginning of the transition.

For flows in concentric cylinder viscometers, the end of the Newtonian laminar regime can be described, if the gap is not too wide, by a constant value of the Reynolds number for a Couette flow,

$$N_{RE} = \frac{V_{R_2} (R_2 - R_1)}{\nu} \quad \ldots\ldots\ldots \quad (164)$$

in which, following the symbols used by Mr. Behn, V_{R_2} in the tangential velocity of the cup, $(R_2 - R_1)$ the gap between the cup and the bob and ν the kinematic viscosity of the fluid. There is no complete agreement as to the numerical

21 "Non-Newtonian Technology," Chapter in "Advances in Chemical Engineering," by A. B. Metzner, Vol. I, Edited by T. B. Drew and J. W. Hoopes, Jr., Academic Press, New York, 1956.

value of the constant,[22] for which values between 180 and 1900 have been suggested.

For the parallel non-Newtonian case, insufficient information is available for the derivation of a similar criterion for the transition. As for the case of flow in a circular conduit, in this case also it is often possible of course to derive a generalized Reynolds number by equating a dimensionless expression for the Newtonian flow in the gap as a function of the Reynolds number of Eq-164, to a similar expression for the non-Newtonian case.

Both for the flow in a circular conduit and in a concentric cylinder viscometer, however, it may at times be difficult to decide from the flow diagrams alone when the flow is laminar or turbulent, and hence to determine the proper values of the rheological parameters (such as n' and K') entering in the definition of the generalized Reynolds numbers. If there is no sharp break in slope at the end of the laminar regime, the rheological parameters could be based on the slopes and intercepts of best-fit lines for the laminar region inadvertently drawn through some points of the turbulent region. Thus, a different criterion for the prediction of the end of the laminar regime is still needed.

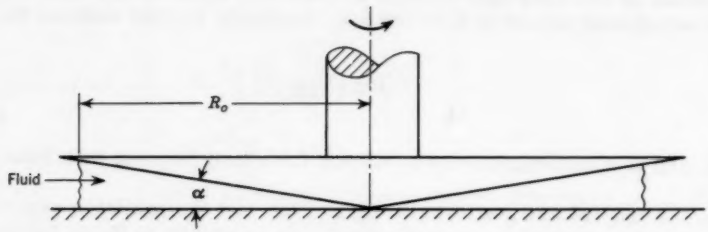

FIG. 2

In addition to concentric cylinder viscometers and capillary viscometers, cone and plate viscometers (Fig. 2) are often used for determining the rheogram of a fluid. For a small value of the average gap, the rate of shear for these viscometers is given by Eq. 165

$$\frac{du}{dy} = \Omega \tan \alpha \quad \ldots\ldots\ldots\ldots \quad (165)$$

in which Ω is the angular velocity of the cone and α the angle between the cone and the plate.[23]

The shear stress is given by Eq. 166.

$$\tau = \frac{3}{2} \frac{M}{\pi R_0^3} \quad \ldots\ldots\ldots\ldots \quad (166)$$

in which M is the torque applied to the cone and R_0 the outer radius of the fluid film between the cup and the plate.

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22 "Boundary Layer Theory," by H. Schlichting, McGraw-Hill Book Co., Inc., New York, 1955.

23 "Non-Newtonian Fluids," by W. L. Wilkinson, Pergamon Press, New York, 1960.

Substitution of Eqs. 165 and 166 into Eqs. 1, 2, and 3 respectively, and subsequent integration leads to the following relations between angular rotation and torque:

for Newtonian fluids

$$\Omega = \frac{1}{\tan \alpha} \frac{3}{2} \frac{M}{\pi R_0^3 \mu} \quad \ldots\ldots\ldots\ldots \quad (167)$$

for Bingham plastics

$$\Omega = \frac{1}{\tan \alpha} \left(\frac{3}{2} \frac{M}{\pi R_0^3 \eta} - \frac{\tau_y}{\eta} \right) \quad \ldots\ldots\ldots \quad (168)$$

for Pseudoplastics

$$\ln \Omega = \ln \frac{1}{\tan \alpha} + \frac{1}{n} \ln \frac{1}{K} + \frac{1}{n} \ln \frac{3}{2} \frac{M}{\pi R_0^3} \quad \ldots\ldots \quad (169)$$

Finally, for time-independent fluids following Eq. 4, the relation between torque and angular rotation is expressed in the general form

$$\Omega = \frac{F(\tau)}{\tan \alpha} \quad \ldots\ldots\ldots\ldots\ldots \quad (170)$$

CHLORINATION OF MIXED SEWAGE AND STORM WATER[a]

Discussion by P. E. Seufer

P. E. SEUFER,[12] F. ASCE.—The synopsis of Mr. Camp's contribution is the best stated indictment against a practice that should be of increasing concern to all sanitary engineers.

Mr. Camp cites several instances of requirements for primary sedimentation that are actually a waste of taxpayers money. Although the United States is one of the richest countries in the world, it cannot afford a waste of its patrimony. Demands on the tax dollar require that sewage treatment be engineered to meet the needs rather than designed to meet some arbitrary standard that should not be applied in the particular situation under design.

To Mr. Camp's example, the writer would like to point out the situation existing with the sewage discharge from an installation in the West. Here a situation exists in which screening, comminution, and chlorination alone would satisfy all the requirements for safe disposal of sewage in a large estuary in which a capability exists for multiple discharge in deep water. The biochemical oxygen demand of the sewage should not be considered in an engineering evaluation of the requirements for sewage treatment for this installation. The raw sewage BOD is only a minute portion of the BOD of the settled sewage discharged from a large plant under less favorable circumstances insofar as the tidal conditions of the receiving water are concerned in the immediate vicinity. This is a salt water discharge of sewage in which recreation is the dominant consideration in the necessity for sewage treatment. Yet, local pollution enforcement authorities are adamant that expenditures of considerable sums of money must be made over and above those for the simple treatment that Mr. Camp's paper so amply demonstrated would suffice.

It is considered that sanitary engineers must be patriotic as well as practicable in their consideration of sewage treatment. The engineer should be permitted to come up with the most economical solution to the problem rather than being burdened with the preconceived conception of what must be built regardless of cost. The money is no longer available to gold plate the nation's sewage treatment requirements and actually never has been!

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[a] January 1961, by Thomas R. Camp (Proc. Paper 2701).

[12] Commanding Officer, U. S. Navy Pub. Works Center, Norfolk 11, Va.

ERRATA

Journal of the Sanitary Engineering Division

Proceedings of the American Society of Civil Engineers

"Marine Disposal of Wastes" Progress Report, Subcommittee on Specialized Subjects, Committee on Sewerage and Sewage Treatments, January 1961, Proc. Paper 2717.

p. 26. In line 34 change 28 to 59 g per l to 28 to 59 μg/l.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 2703 is identified as 2703(ST1) which indicates that the paper is contained in the first issue of the Journal of the Structural Division during 1961.

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MAY: 2460(AT1), 2461(ST5), 2462(AT1), 2463(AT1), 2464(CP1), 2465(CP1), 2466(AT1), 2467(AT1), 2468(SA3), 2469(HY5), 2470(ST5), 2471(SA3), 2472(SA3), 2473(ST5), 2474(SA3), 2475(ST5), 2476(SA3), 2477(ST5), 2478(HY5), 2479(SA3), 2480(ST5), 2481(SA3), 2482(CO2), 2483(CO2), 2484(HY5), 2485(HY5), 2486(AT1)[c], 2487(CP1)[c], 2488(CO2)[c], 2489(HY5)[c], 2490(SA3)[c], 2491(ST5)[c], 2492(CP1), 2493(CO2).

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FEBRUARY: 2726(WW1), 2727(EM1), 2728(EM1), 2729(WW1), 2730(WW1), 2731(EM1), 2732(SM1), 2733(WW1), 2734(SM1), 2735(EM1), 2736(EM1), 2737(PL1), 2738(PL1), 2739(PL1), 2740(PL1), 2741(EM1), 2742(ST2), 2743(EM1), 2744(WW1), 2745(WW1), 2746(SM1), 2747(WW1), 2748(EM1), 2749(WW1), 2750(WW1)[c], 2751(EM1)[c], 2752(SM1)[c], 2753(PL1)[c], 2754(ST2)[c], 2755(PL1).

MARCH: 2756(HY2), 2757(IR1), 2758(AT1), 2759(CO1), 2760(HY2), 2761(IR1), 2762(IR1), 2763(HY2), 2764(ST3), 2765(HY2), 2766(HW1), 2767(SA2), 2768(CO1), 2769(IR1), 2770(HY2), 2771(SA2), 2772(HY2), 2773(CO1), 2774(AT1), 2775(IR1), 2776(HY2), 2777(HY2), 2778(SA2), 2779(ST3), 2780(HY2), 2781(HY2)[c], 2782(HW1)[c], 2783(SA2)[c], 2784(CO1), 2785(CO1)[c], 2786(IR1)[c], 2787(ST3)[c], 2788(AT1)[c], 2789(HW1).

APRIL: 2790(EM2), 2791(SM2), 2792(SM2), 2793(SM2), 2794(SM2), 2795(SM2), 2796(SM2), 2797(SM2), 2798(EM2), 2799(EM2), 2800(EM2), 2801(EM2), 2802(ST4), 2803(EM2)[c], 2804(SM2)[c], 2805(ST4)[c].

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c. Discussion of several papers, grouped by divisions.

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